AD 400 960

FEDERAL AVIATION AGENCY

SYSTEMS RESEARCH AND DEVELOPMENT SERVICE

ECONOMIC IMPACT OF WEATHER INFORMATION ON AVIATION OPERATIONS

FINAL REPORT CONTRACT NO. FAA/BRD-410

PROJECT NO. 151-15

30 SEPTEMBER 1962

PREPARED FOR

FEDERAL AVIATION AGENCY

SYSTEMS RESEARCH AND DEVELOPMENT SERVICE

by

E. BOLLAY ASSOCIATES, INC.

SANTA BARBARA, CALIFORNIA

Best Available Copy

6

ECONOMIC IMPACT OF WEATHER INFORMATION ON AVIATION OPERATIONS

Final Report
12 Contract FAA/BRD-410
Project No. 301-1S

5 see page V

16 ...
7 ...
12 NA
13 Final
15 NA

9 30 September 19..

This report has been prepared by E. Bollay Associates, Inc. for the Systems Research and Development Service, formerly the Bureau of Research and Development, Federal Aviation Agency under Contract FAA/BRD-410. The contents of this report reflect the views of the contractor who is responsible for the facts and accuracy of the data presented herein. The content of this report does not necessarily reflect the official policy of the Federal Aviation Agency.

E. BOLLAY ASSOCIATES, INC.
1715 State Street
Santa Barbara, California

5 127 850

ABSTRACT

E. Bollay Associates, Inc., Santa Barbara, California
ECONOMIC IMPACT OF WEATHER INFORMATION ON AVIATION OPERATIONS, September 30, 1962, 305 pp., 47 illus., 7 appendices, Final Report (Contract No. FAA/BRD-410)

The Administrator of the Federal Aviation Agency is charged with the responsibility of assuring the safe and efficient utilization of the nation's airspace. Weather affects both safety and efficiency and a reduction of its harmful influences is an important matter of concern to the Agency.

The Agency has determined the weather information required by all airspace users during the period from the present through 1975 to produce the maximum possible reduction in weather effects upon the users operations, and is now designing the Common Aviation Weather System (CAWS) to provide the needed information. The implementation of this system will involve the expenditure of additional funds above that presently devoted to aviation weather support. It is the purpose of this study to weigh the benefits to be derived from the CAWS against the additional costs involved and, in so doing, to provide an objective means of comparing the returns to be received from such expenditures with those which might result from expenditures for other aviation support functions.

Benefit to cost ratios were determined in two ways. The first method computes the ratio of the present value of total benefits, through 1975, with present value of total costs; this yields a ratio of 2 to 1.

In the seond method an annual benefit/cost ratio is computed for the 1970-75 time period. This ratio, which reflects conditions after CAWS implementation is complete, is 3 to 1.

PREFACE

This volume describes the results of a one year study to determine the economic effects of weather information on aviation operations are described. The report presents estimates of the economic penalties to aviation caused by inadequate weather information, the cost of implementing an improved aviation weather system, the economic benefits that such a system can bring, and finally, the expected benefit to cost ratio.

The net result of the study is a picture of the economic return that our country reasonably can anticipate from the allocation of Federal funds to improved aviation weather support.

~~The many Agencies, private companies and individuals who helped - through consultation or statistical information - in the preparation of this report are listed in the Appendix. Their assistance is gratefully acknowledged.~~

8

Eugene Bollay
E. BOLLAY ASSOCIATES, INC.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd.)

TABLE OF CONTENTS
(Cont'd.)

LIST OF FIGURES

LIST OF FIGURES (Cont'd.)

LIST OF FIGURES (Cont'd.)

LIST OF FIGURES (Cont'd.)

LIST OF TABLES

LIST OF TABLES (Cont'd.)

LIST OF TABLES (Cont'd.)

LIST OF TABLES (Cont'd.)

LIST OF TABLES (Cont'd.)

LIST OF TABLES (Cont'd.)

LIST OF TABLES (Cont'd.)

INTRODUCTION AND SUMMARY

The Administrator of the FAA has the responsibility to assure the safe and efficient utilisation of the nation's airspace by all users. Weather affects both the safety and efficiency of airspace usage; the reduction of its harmful influences is an important concern of the Agency. The weather sensitivity of aviation operations can be reduced or eliminated by:

- Making air operations independent of weather - through all-weather flight control systems
- Changing the weather to suit air operations - by weather modification
- Adapting operations to existing and future weather conditions - through accurate and timely weather forecasts

It is likely that some elements of civil and military aviation will be independent of weather effects by 1975, but these will be the exception rather than the rule. It is not likely that the operational use of weather modification techniques will contribute to the reduction of weather effects by 1975. For these reasons, the present emphasis in aviation weather support is on improving both the accuracy and accessibility of weather information given to operational users - pilots, ground crews, dispatchers, and the air traffic control system.

The Agency has determined the weather information needed by operational users in the time period NOW-1975[1]; it is designing the Common Aviation Weather System (CAWS)[2] to provide the needed information. The satisfaction of aviations' requirements for weather information is certainly desirable, but the practical questions of its cost and benefit must be answered to give perspective to this one need among the many that require financial support. This report contains the data that will be required for an objective comparison of aviations' weather support needs with those of other

[1] National Aviation Meteorological Requirements Through 1975, FAA, SRDS, Oct 61

[2] Common Aviation Weather System Design - Report No. 2, FAA, SRDS, Aug. 1962

aviation support functions. The report presents its results as the ratio of economic benefits of improved weather service to the increased cost of that service.

Figure I-1 illustrates the analytical path followed in the study. First, the total weather penalties to aviation were computed using statistics for 1960 - the most recent year for which complete data are available. Next, those penalties caused by inadequate weather information - not weather itself, but adequate knowledge of the weather - were isolated. FAA traffic density and user spectrum projections were then used to forecast the value of the penalties in the years between 1960 and 1975. Year by year benefits were obtained by estimating the reduction in penalties that could be expected from CAWS operation. Finally, the benefits through 1975 were brought to a present value - 1963 - so that they could be compared with the projected additional weather service cost through 1975.

The additional cost of improved service was estimated by subtracting from the projected year by year cost of CAWS operation the cost of the present civil aviation weather services. The difference-through 1975 - was then brought back to a present value at 1963. From the benefit and cost data, benefits/cost ratios were computed in two ways; first as the ratio of total benefit to total cost, and secondly, as annual benefit to annual cost. These results describe in economic terms, not only the total effects of improved service, but also their year by year variation.

This study does not treat the economic aspects of military aviation weather support because definitive service cost data were not available to the investigators. The study further confines itself to benefits that are assessible; intangible benefits to other user segments - agriculture, shipping, surface transportation for instance - were not included, although they will be present.

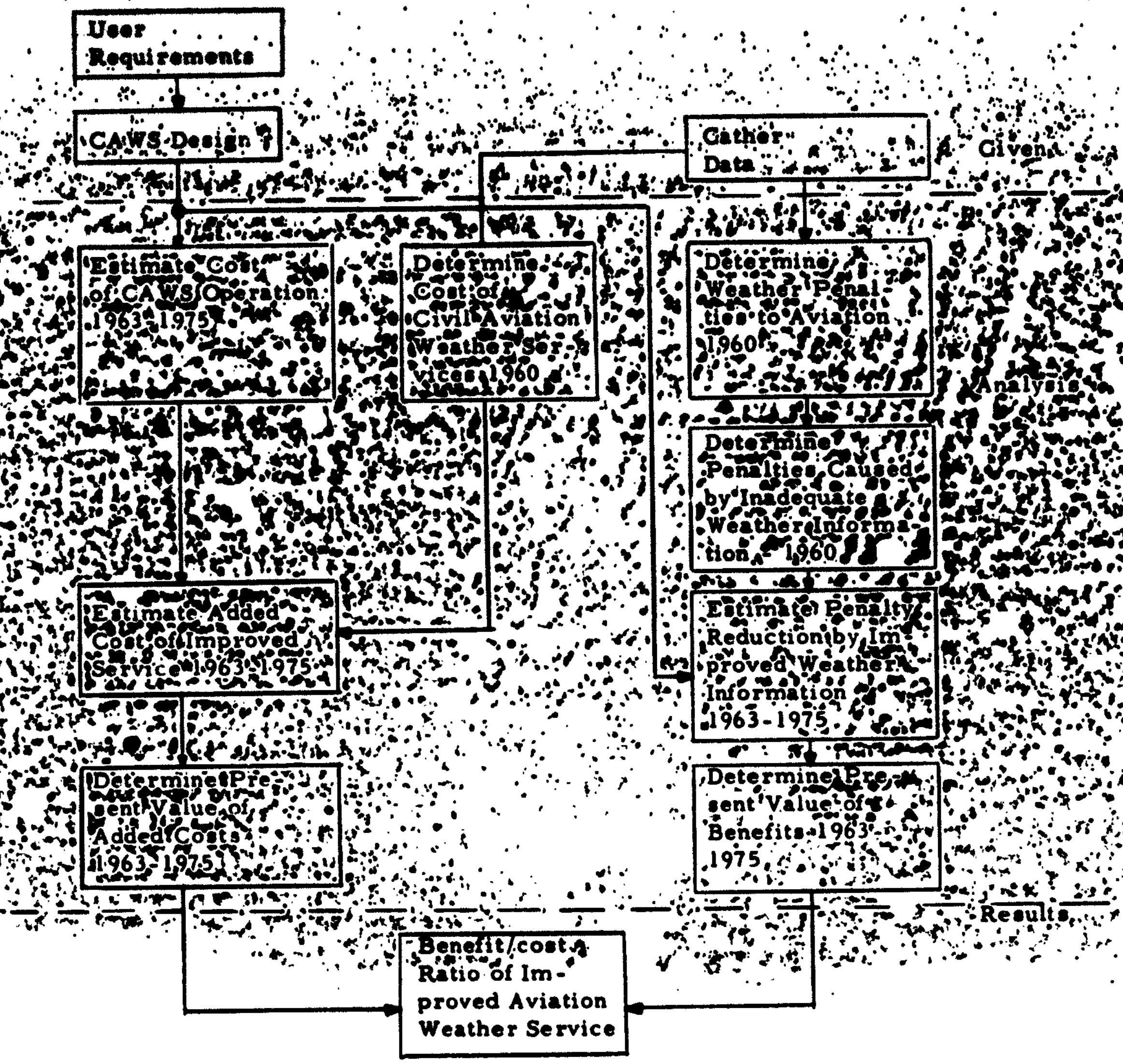

Figure I-1. Steps in the Study

WEATHER PENALTIES TO AIRSPACE USERS

There are three categories of non-military airspace users; commercial air carriers, general aviation and the air traffic control system. The weather penalties suffered by each category were determined from actual operating histories - in the case of air carriers - or from government statistics - for general aviation and the air traffic control system. These penalties were then projected through 1975 by considering the expected traffic density increase and the gradual change in the spectrum of aircraft types.

Weather-caused losses to air carriers include:

- In-flight delays - unexpected conditions that result in increased flight time and higher direct operating costs.
- Passenger delays - the value of passenger time lost in in-flight delays.
- Maintenance delays - the increased cost of off-schedule maintenance operations
- Alternate and contingency fuel loads - the cost of carrying fuel reserves for unexpected weather conditions
- Diversions - the cost of additional operating time and passenger services when scheduled aircraft divert to alternate airports
- Cancellations - the revenue lost when a flight does not operate, reduced by the direct operating cost saved by not flying.

Table I-1 summarizes the air carrier losses in the base year, 1960, and the projected losses through 1975.

Table I-1. Weather Caused Losses to Air Carriers (rounded to nearest million dollars)

Cause	1960	1965	1970	1975
In-flight Delays	$8.	$9.	$10	$10
Passenger Delays	20	25	33	48
Maintenance Delays	9	11	13	14
Alternate and contingency fuel loads	7	39	71	106
Diversions	5	7	10	11
Cancellations	6	6	11	18
Total	$55	$97	$148	$207

While weather causes a reduction in the efficiency of air carrier operations, it affects primarily the safety of general aviation operations. This is shown in Table I-2. where the cost of general aviation fatalities and injuries far outweighs the cost of lose aircraft or the value of in-flight time delays.

Table I-2. Weather Caused Losses to General Aviation (rounded to nearest million dollars)

Cause	1960	1965	1970	1975
Casualties	$139	$179	$223	$270
Aircraft damage	11	14	17	18
Delays	13	18	23	30
Total	$164	$211	$263	$318

The present air traffic control system uses weather information largely for planning purposes; it does not employ weather information to optimize its real time operation. The economic losses to aviation caused by ATC operation without adequate weather support are difficult to determine; they are a function of both weather information and present air traffic control procedures. The losses due to weather caused ATC delays were estimated by first, computing the value of all ATC delays, then assuming the preponderance of them to be terminal area delays and, finally, assigning 10% of these delays to weather causes alone. These computations lead, in the most conservative case, to losses varying from $8 million in 1960 to $21 million in 1975.

Figure I-2 shows the total projected weather penalties to all three airspace user categories. Total losses vary about linearly between $225 million in 1960 and $550 million in 1975. Part I of this report discusses, in detail, the weather-caused economic losses to aviation.

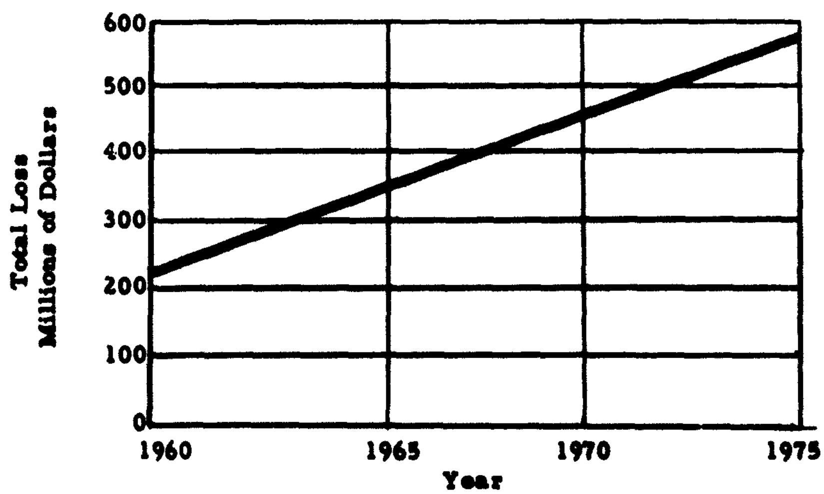

Figure I-2. Total Weather Caused Economic Losses to Airspace Users

COST OF CURRENT AVIATION WEATHER SERVICES

The FAA and the Department of Commerce (U. S. Weather Bureau) share about equally in funding the current civil aviation weather service. Table I-3 shows the costs associated with each major function of the service, weather observation, data processing and forecasting, presenting products to users and communicating data within and outside of the system. It includes research and development and supporting activities.

Table I-3. Cost of Current Civil Aviation Weather Services
(rounded to nearest million dollars)

Function	FAA	USWB	Total
Observing	$1	$15	$16
Processing	-	6	6
Presenting	4	3	7
Communicating	14	2	16
Research and Development	6	1	7
Administration	3	2	5
Total	$28	$29	$57

The military also make appreciable contributions to the civil aviation weather service by providing many weather observations. These benefits are received as an outgrowth of the primary military preparedness mission; their costs are not included here since the function must be performed regardless of the particular civil need.

Part II of this report presents an analysis of the current costs of the civil aviation weather services.

THE COST OF IMPROVED AVIATION WEATHER SERVICE

Improved aviation weather support will cost money; the study estimated the cost of CAWS implementation to determine how much additional cost is involved. Detailed cost estimates were made for each major function in the system - observing, processing, presenting and communication - and then grouped into two major categories. The first category is equipment costs, which require capital investment; the second category is operating costs which include recurring items such as salaries and maintenance.

Figure I-3 shows the total estimated annual cost of CAWS implementation above that of the existing aviation weather services. It also shows the equipment and operating costs that make up the total. For the purposes of this study, equipment costs stop after 1970 when the CAWS will be completely implemented.

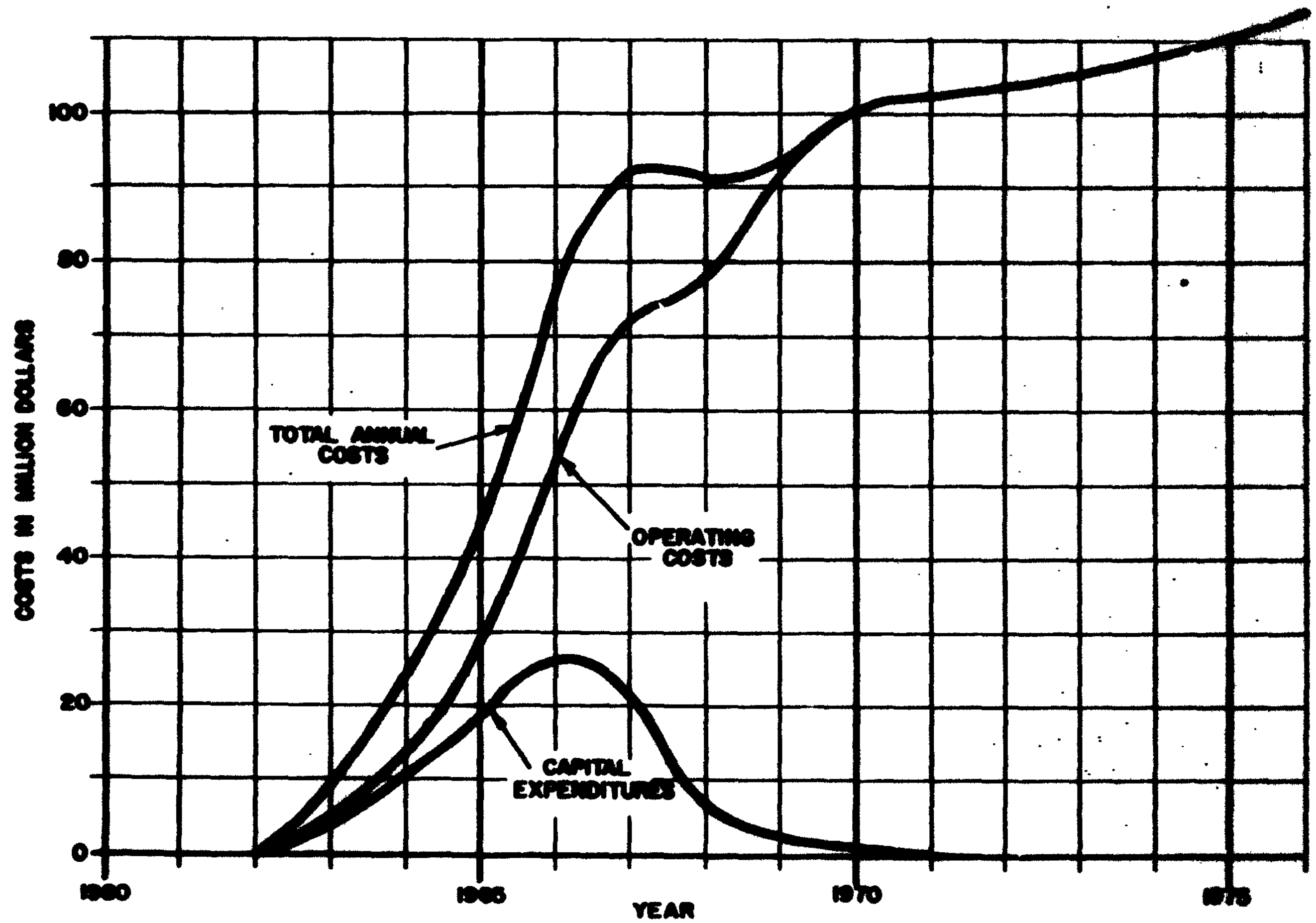

FIGURE I-3. ESTIMATED IMPLEMENTATION COSTS IN MILLION DOLLARS

THE BENEFITS OF IMPROVED AVIATION WEATHER INFORMATION

The next step was to estimate the proportion of the total weather caused penalties which was due to lack of or inadequate weather information as opposed to weather per se, and hence susceptible to reduction and/or elimination through improved accuracy, timeliness and availability of weather information. These values are presented in Table I-4.

Table I-4. Total Losses Due to Inadequate Weather Information
(millions of dollars)

User Category	1960	1965	1970	1975
General Aviation	123	159	197	240
Air Carriers	9	19	31	44
ATC System	11	14	18	22
Total	143	192	245	306

The primary benefit to air carriers is in reducing the amount of unexpected weather delays and the need to carry large fuel reserves. General aviation benefits most from the reduction of fatalities caused by VFR flights into unexpected IFR weather. An air traffic control system operation that responds to accurately known or forecast weather conditions further reduces delay penalties to controlled flights.

The study assumes that some features of the CAWS will be implemented in 1963 and that the system will be fully implemented by 1970-71. The benefits of the system's operation will lag its implementation because airspace users will require some time to take advantage of the system performance in their day-to-day operations. As airspace users progressively apply the improved weather information, the nation can expect the economic benefits shown in Figure I-4.

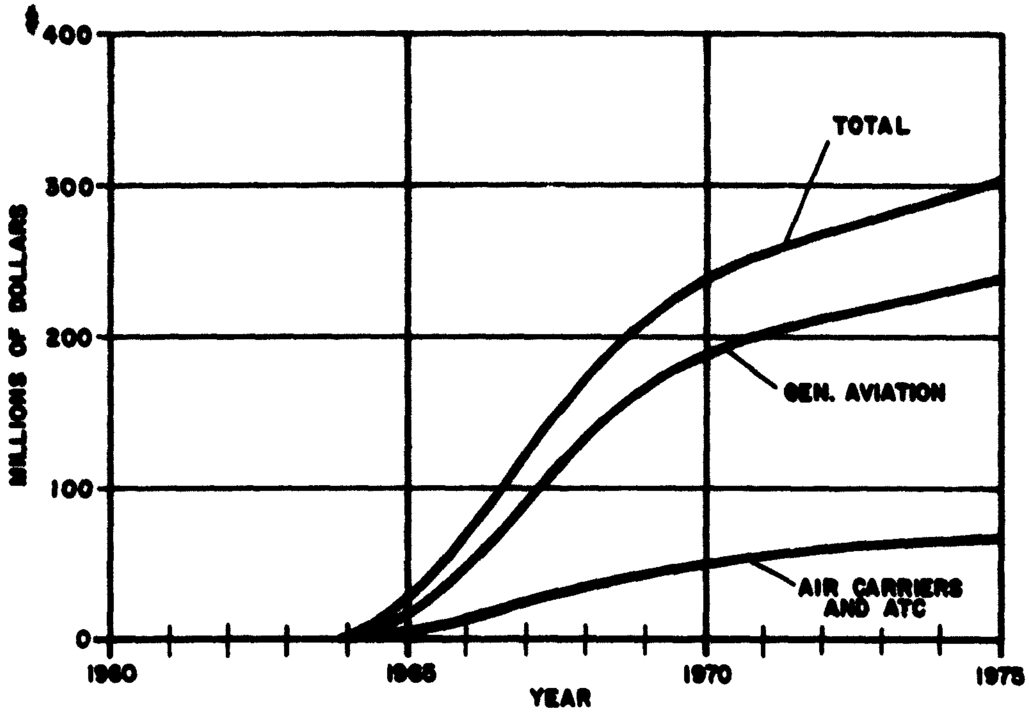

FIG. I-4. ESTIMATED TOTAL DOLLAR BENEFITS FROM IMPROVEMENTS IN AVIATION WEATHER SERVICES

BENEFIT/COST RATIOS

Benefit-to-cost ratios are a convenient way to express the comparison between the return on an economic expenditure and its cost. This study presents benefit-cost ratios computed in two ways.

In the first method, the total value of benefits and costs for each year 1963 through 1975 is converted to the present value, 1963, through use of the cumulative interest formula. The benefit-to-cost ratio computed in this manner yields a value of 2.0.

In the second method an average annual benefit-to-cost ratio is computed for the years 1970-1975. This value, which represents conditions after implementation of the CAWS is complete, is 3.0.

Part III of this report examines in detail the cost of improved aviation weather service and the benefits of such service and then makes benefit/cost comparisons.

Figure I-5 presents the annual costs and annual benefits through 1975 due to CAWS implementation.

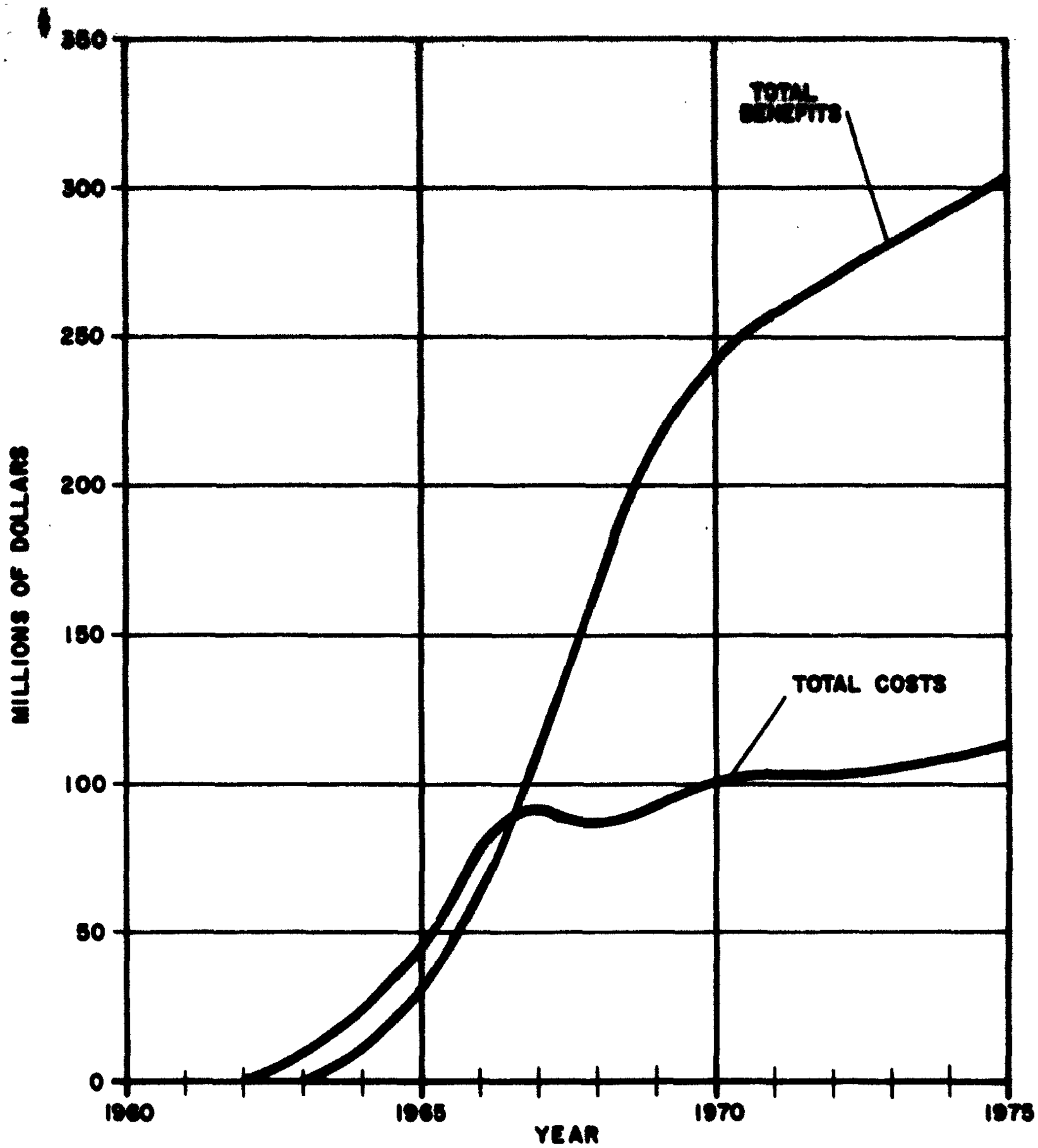

FIG. I-5. PROJECTED TOTAL COSTS AND TOTAL BENEFITS, DUE TO CAWS IMPLEMENTATION

PART I

A. AIR CARRIER PENALTIES

PART I

PENALTIES DUE TO WEATHER

A. AIR CARRIER PENALTIES

General Considerations

1. In Flight and On Ground Delays

   a. In Flight Delays
   b. In Flight Gains
   c. On Ground Delays

2. Passenger Time Lost due to Delays

   a. Cost per Passenger Hour
   b. Cost of Passenger Delay

3. Maintenance and Ground Support

4. U. S. Mail Delays

5. Alternate and Contingency Fuel

6. Cancellations

   a. Number of Cancellations due to Weather
   b. Interrupted Trip Expense
   c. Cost of Cancellations

7. Diversions

8. Off-Loading Due to Elevated Runway Temperatures

9. Summary of Total Penalties

GENERAL CONSIDERATIONS

In this section, the various penalties incurred by the air carriers due to weather causes have been identified. These penalties range over a broad spectrum, covering such items as terminal and enroute delays, the carrying of alternate and contingency fuel reserves unnecessarily, off-loading of revenue cargo due to elevated temperatures, disruptions to maintenance scheduling, etc.

For each penalty so identified, a quantitative estimate was made of the economic loss to the domestic air carriers as a whole as well as the loss to the travelling public. In this section, the penalties imposed by weather in all its aspects were evaluated. Secondary effects, such as the effect of weather on the ATC system, have been studied separately and are presented in Part I. C. of the report.

To evaluate the effect of potential improvements in the aviation weather service, it was then necessary to examine each penalty and separate from the total that portion which was the result of lack of or inadequate weather information. This portion of the analysis has not been attempted in this section but is presented in Part III B.

In making projections of these penalties through the year 1975, heavy reliance has been placed on the forecasts of air carrier activity in that period prepared by the Federal Aviation Agency.[1]

---

[1] "Forecasts of Air Traffic Activity, CONUS 1960-1975", Traffic Analysis Branch, Aviation Research and Development Service, Federal Aviation Agency.

PART I

PENALTIES DUE TO WEATHER

A. AIR CARRIER PENALTIES

1. In-Flight and On-Ground Delays

a. In-Flight Delays

Each year the air carriers incur delays in flight which are caused primarily by weather factors. The deviations from established flight schedules can reflect other influences such as the relative "tightness" of the schedule, and the type of equipment flown. In this section only delay in the actual flight segment will be considered; on-ground delays will be discussed in a subsequent section.

Airline schedules are usually constructed from the aircraft specifications after customer demand is projected, and are further tailored to reflect certain known operating effects of such parameters as local weather, ATC problems, field or ramp congestions, gate availability, location of ground support equipment, flight crew requirements, and maintenance schedules. The schedule is released and the operating performance observed. After some operational experience, the schedule can be re-examined and refined to reflect "the facts of life" for each segment.

Flexibility in scheduling is useful and necessary for the quality of the product; however it is also expensive. For example, one minute of "flexibility" or "pad" built into the 1960 schedules for each turbojet flight would have cost $1,235,000 per year[1]. This is an expense not likely to be overlooked by air carrier operators. A schedule produced directly from the operating manual of the aircraft rarely meets the requirements of reliable service because of the many other factors involved, some of which are capable of modification, while others are inherent in the system. The necessary schedule "pads" cannot be reduced unless some of the delaying parameters themselves are reduced or at least made more predictable or consistent.

---

[1]Cited, pg. 1. In 1960 Turbojets made 100,000 flights. One minute/flight = 1676 hrs. From: CAB Form 41, Summary, Calendar year 1960. Weighted Overall Hourly Operating Costs, Turbojets $960, Less Hourly Fuel Costs $225, Net $735. Thus: $735 x 1676 hrs. = $1,235,000

In addition, any delay, regardless of cause, represents a deviation from planned utilization of the aircraft. Statistically, a scheduled aircraft, when delayed enroute for any cause, ultimately loses its capacity for producing revenue to the extent of the delay.

Deviations from schedule due to weather factors are a prime area for refining air carrier operation and minimizing operational expenses, through the application of more accurate weather forecasts to the operational planning functions. Undesirable effects can be minimized and potential gains can be realized.

Reported Delays

The primary weather parameters affecting flight are:

- Winds aloft
- Turbulence
- Severe weather areas (squalls, thunderstorms)
- Altitude changes
- Temperature
- Icing

Winds at cruising altitudes of turbojet airliners (25,000 to 39,000 feet) can assume considerable magnitudes. The well known "jet streams" are found at these altitudes. They are large bands of air currents with a high speed core where peak velocities near 300 knots have been measured and with average velocities ranging around 150 knots in the winter. During the summer months these velocities are considerably lower, averaging 50-75 knots.

Appreciable delays from scheduled flight times due to adverse winds are experienced by carrier flights, especially on longer haul trips. Conversely, time gains could be realized through accurate knowledge of the location and intensity of such winds. However, due to scheduling problems, gate availability, etc. arrival ahead of schedule is undesirable and normally avoided.

Turbulence areas encountered enroute usually require the airplane to be slowed down for reasons of passenger comfort as well as to reduce the aircraft's gust loads. These may be avoided by re-routing or by change of altitude if known in advance. Areas of clear air turbulence at present cannot be forecast accurately, except in a probabilistic fashion. Aircraft can only be fore-warned by other flights passing through these regions.

In addition to the delays resulting from reduced airspeed, turbulence produces other penalties such as passenger injuries and aircraft damage. These items are considered separately from the purely operational losses and are dealt with in another section.

Severe weather areas, such as squall lines or thunderstorms must be circumvented since they constitute severe hazards to safe flight. This causes an increase in flight time with resulting late arrivals.

Altitude changes are frequently required by aircraft to avoid weather hazards.

Temperature deviations from forecast values affect engine performance and can result in loss of thrust and a corresponding reduction in speed. In comparison with winds and turbulence, the temperature factor in flight delays is relatively unimportant.

Icing in clouds is likewise of secondary significance for the present turbojets. However, it can cause measurable delays for propeller driven aircraft and still poses a serious safety problem to this type of aircraft.

In this analysis of the effects of weather on in-flight performance, reported data have been used from a total of 270,378 piston flights and 55,088 turbojet flights of a domestic trunk carrier. This carrier, because of its extensive operations, both north and south as well as east and west, comprising both local as well as trunk line operations over a large segment of the

U.S., is representative of U. S. domestic air carrier operations. It is considered one of the most accurate sources available for this information. From these data, the over-all effects of weather factors on in-flight performance of the domestic air carriers have been estimated.

Detailed pilot reports were collected on in-flight delays caused by weather factors. In completing this delay analysis form, the pilot of the aircraft reported actual gains and losses for each flight segment due to such factors as winds aloft, altitude, turbulence, detour, temperature and other parameters. The period during which these reports were made, extends over 1 1/2 years, from January 1960 through July 1961. The combination of short haul as well as long haul flights, both piston and turbojet, flown by this carrier, and the methods used for reporting the delays, provided a rational basis for applying the data to the total U. S. domestic carrier operations.

Figure 1 shows the weather delays expressed in minutes per flight and in percentage of average flight duration for turbojet aircraft during the period from January 1960 to July 1961. Since this particular carrier was at that time inaugurating its first turbojet flights, the total number of flights per month is seen to increase from a low of 634 in January 1960 to 6219 in June 1961. Along with this increase in activity the curves of weather delays show a decrease and a subsequent leveling off in the period September 1960 to July 1961.

Figure 2 shows the weather delay for propeller aircraft operation of the same carrier. These delays reveal a clearly discernible seasonal pattern with a high in the February-March period and a low in the summer months from July to October. Since this analysis endeavors to compute annual cost figures rather than seasonal breakdowns of costs, the average delay over a representative one year period; July 1960 to

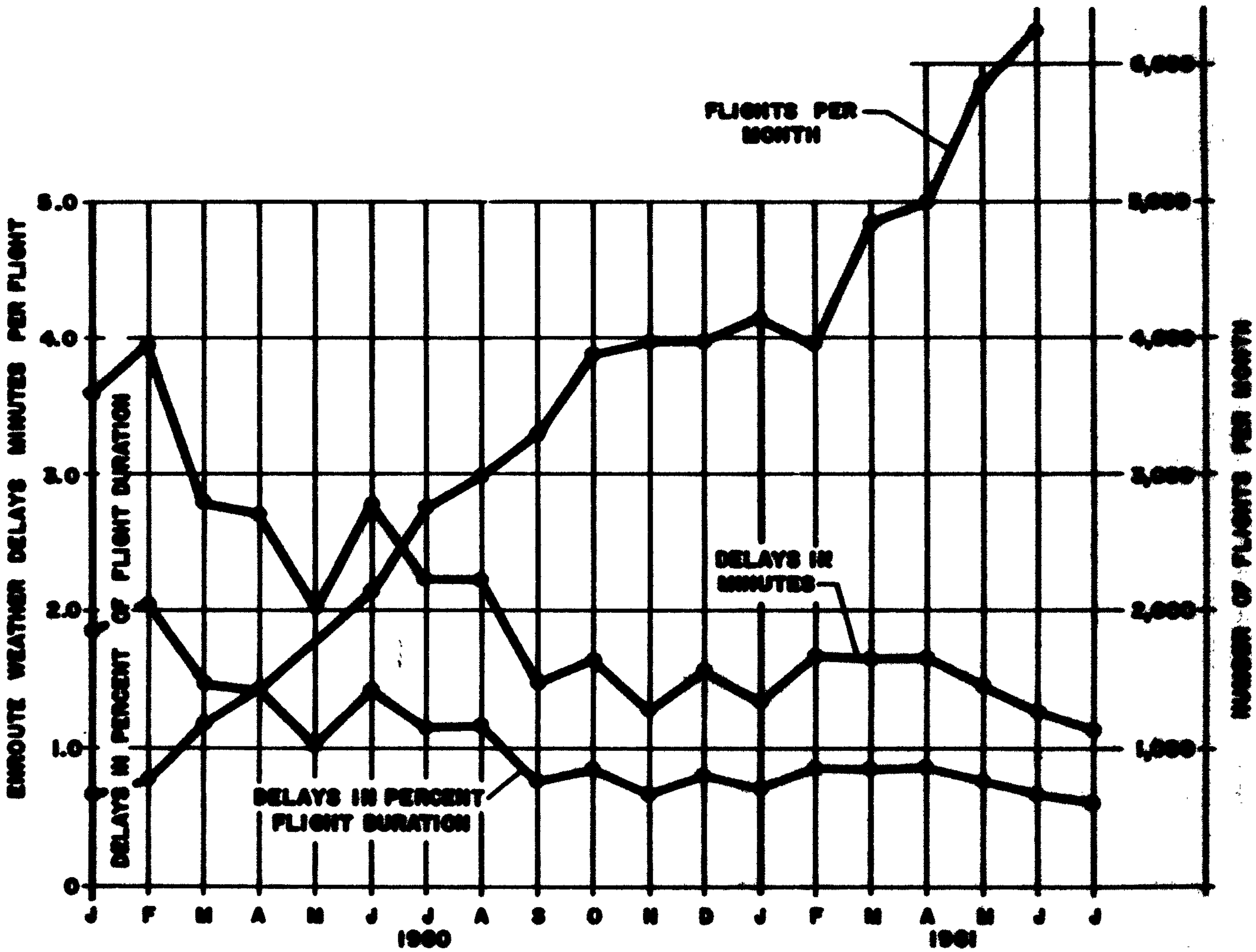

FIGURE I. TURBOJET AIRCRAFT, ENROUTE DELAYS CAUSED BY WEATHER FOR TYPICAL DOMESTIC AIR-CARRIER, JAN. 1960 - JULY 1961

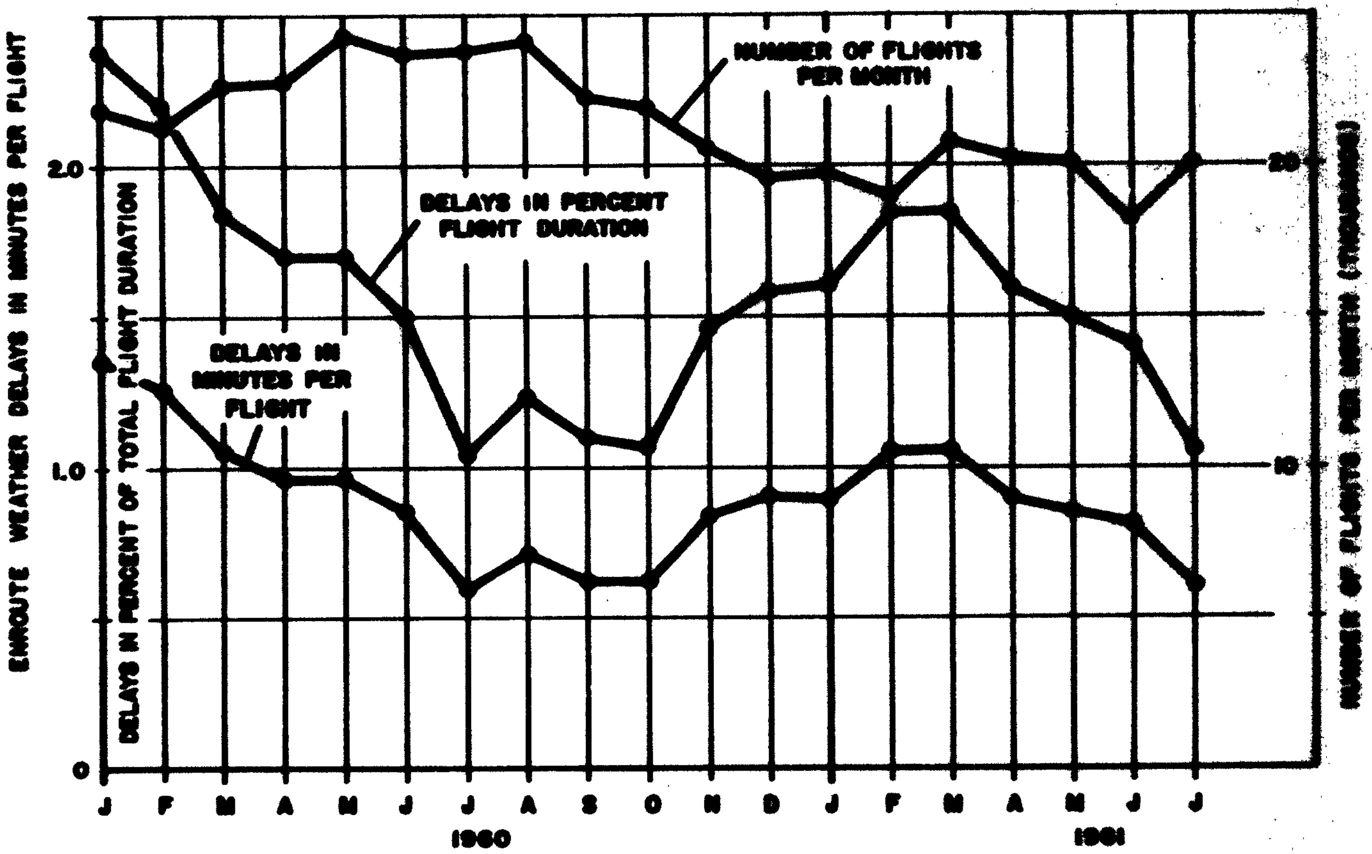

FIGURE 2. PROPELLER AIRCRAFT, ENROUTE DELAYS CAUSED BY WEATHER FOR TYPICAL DOMESTIC AIR-CARRIER JAN. 1960 - JULY 1961

July 1961 has been computed and used in subsequent cost estimates. The figures give the average delay per flight for all flights. Subsequently in this study the actual flights delayed will be considered with the average delay per delayed flight.

These weather delays per flight are somewhat conservative, since they were computed from operational records of a major trunk carrier with a well-staffed meteorological department. Some of the trunks and most of the thirteen local carriers have no meteorological services of their own and consequently do not have this advantage.

The total in-flight delays due to weather, projected over the domestic air carrier fleet in 1960-1961, amounted to 2632 hours for the turbojet fleet and 41,890 hours for all types of propeller-driven aircraft, including turboprops. The relative percentages of the total losses due to the individual weather factors indicate clearly the predominance of the wind factor. This factor accounts for 77% of all weather delays for both turbojets and propeller aircraft. These delays constitute a net value in which both the delaying effect of head winds and the limited offset from tail winds has been taken into account. Turbulence accounts for only 11.5% of the turbojet delays and for 15.8% of the propeller delays, while altitude is the reason for some 6-7% of in-flight delays for both prop and turbojet.

Temperature and change of altitude are relatively minor delay factors. Efforts to reduce their impact are of less importance especially since change of altitude is more often determined by ATC considerations, and temperature is at present fairly accurately forecast, measured and reported enroute by aircraft in flight. Temperature delays account for only 4.5% of the total weather delays. A breakdown of total hours of in-flight delay by equipment and by weather factor is shown in Figure 3.

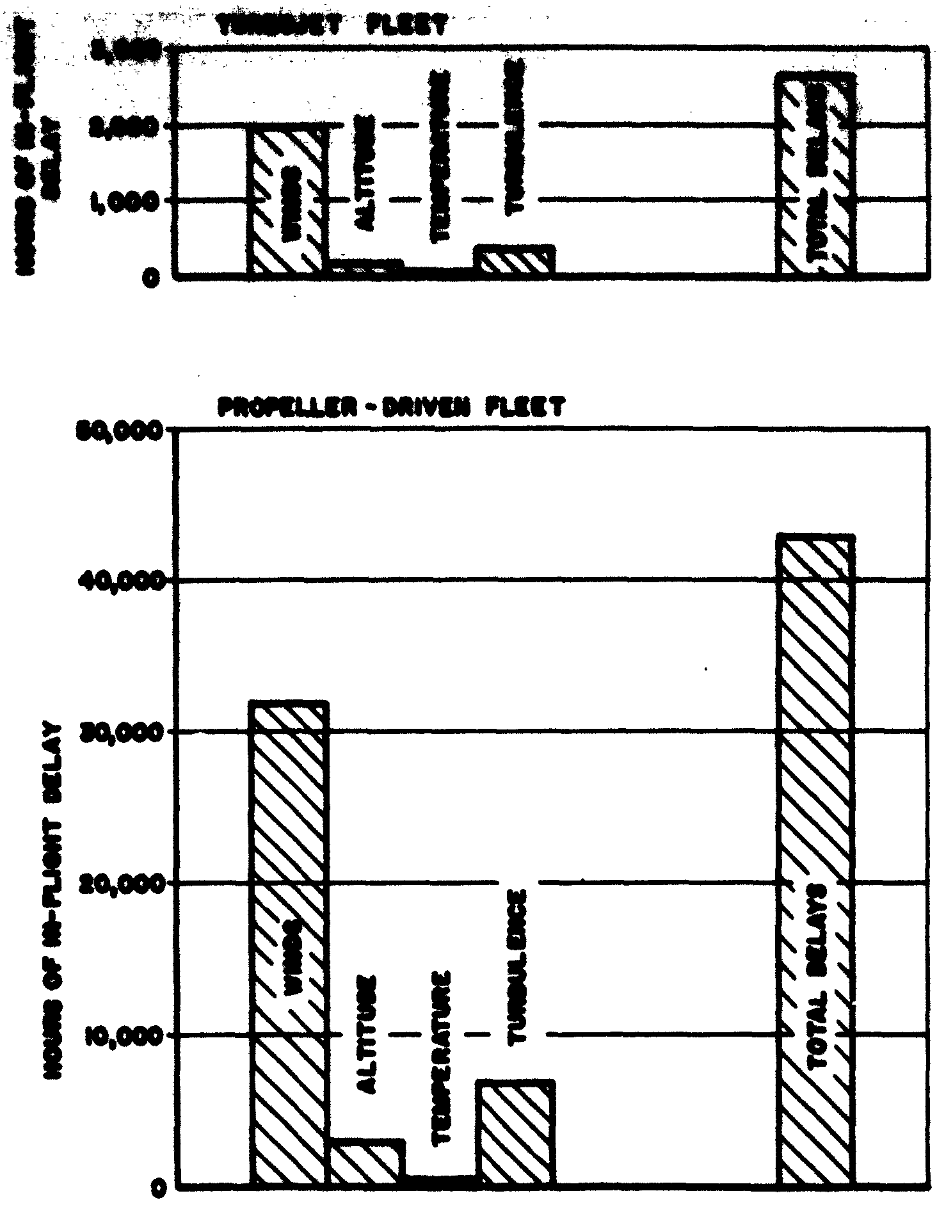

FIGURE 3. IN-FLIGHT DELAYS DUE TO WEATHER CAUSES, DOMESTIC CARRIERS (AUG. 1960 - JULY 1961)

In computing the economic effects of these delays, consideration must be given to the methods of reporting such delays. Some of the delays are counterbalanced by gains on the same flight, resulting in on-schedule arrivals of the aircraft. Others produce delayed arrivals to the extent of the reported delay. A loss due to turbulence, for example, can be made up for the same flight if there is a corresponding gain due to favorable winds. Conversely, the losses from all causes for a particular flight can be cumulative and result in a gross delay in arrival time.

A survey was made of the delay reports in order to arrive at an estimate of the percentage of losses counter-balanced by equivalent gains. The results indicate that approximately 25% of the trips experiencing losses will have these losses offset by the gains on the same flight; the remaining 75% will result in delayed arrivals. Accordingly, the reported losses are pure losses only to the extent that they cause a late arrival for the particular trip. In arriving at a representative economic penalty for such in-flight delays, 75% of the losses reported will be considered here at the full operating cost of the aircraft.

There are other undesirable effects from weather delays which indicate that this procedure may under-estimate the penalties. In-flight delays not only affect one particular flight but extend to connecting flights as well. There is frequently a chain effect upon future aircraft schedules, which effect may extend over periods of several days. This factor has been omitted here, since no representative data are available.

On the basis of the above premises, the net dollar costs of in-flight delays due to weather of the U. S. domestic carriers in 1960 can be calculated. Average hourly operating costs of $960.00 for turbojets and $320.00 for piston aircraft have been computed from CAB summary Form 41, Calendar Year 1960, Domestic Operations. (See Appendix B). These

total direct hourly operating costs have been modified by eliminating all indirect maintenance costs and 50% of the depreciation, giving a factor of 78.6%, in order to make them applicable to in-flight delays. (Table 1, column 3.) Multiplying these hourly costs by the total hours of delay in 1960 yields the total dollar losses due to in-flight delays in 1960, Table 2. Turboprop aircraft were included in the propeller driven category because of their similarity in operating costs as well as performance to some of the higher performance piston aircraft.

b. In-Flight Gains

Upper air head winds which cause delays enroute in one direction will be tail winds and shorten the flight time in the opposite direction. The flights primarily affected are the East-West transcontinental trips because of the fact that the jet streams have a predominately West to East component.

Table 1. Total Direct Operating Costs

For delays in flight and ATC delays the entire direct operating cost per hour is reduced by one half the depreciation and all of the indirect maintenance costs. For diversions, the entire direct operating costs are used. The following table reflects these refinements.

	% Total Direct Operating Cost[1]	Direct Oper. Cost/Hour from CAB-41	Hourly Cost Delayed Flight % Total		Hourly Cost Diversion	
Crew Salary	8.8%	100%	100	8.8	100	8.8
Insurance	15.6	100	100	15.6	100	15.6
Fuel	23.5	100	100	23.5	100	23.5
Direct Maintenance	19.2	100	100	19.2	100	19.2
Indirect Maintenance	10.0	100	0	0	100	10.2
Depreciation	22.9	100	50	11.5	100	22.9
TOTALS	100%	100%		78.6%		100%

[1] See Table 5.

Table 2. Net Operating Costs of In-Flight Delays Due to Weather - U. S. Domestic Carriers, 1960 - 1961

	DELAYS		
	Net Delays Hours	Operating Cost per Hour[1]	Net Delay Costs
Turbojet Aircraft			
Winds	1537	$755	$1,160,000
Altitude	121		91,000
Turbulence	227		171,000
Temperature	71		54,000
TOTAL	1956		$1,476,000
Propeller Aircraft			
Winds	21400	$252	$5,393,000
Altitude	2300		580,000
Turbulence	4960		1,250,000
Temperature	----		---------
TOTAL	28660		$7,223,000

[1]78.6% of total direct operating cost; see Tables 1 and 5.

Thus, transcontinental flights can take advantage of existing winds aloft by the judicious selection of altitude and routings to meet scheduled flight times or decrease fuel consumption within the scheduled flight duration. The same also applies to North-South flights but to a much smaller degree. It is possible to make use of favorable wind conditions simultaneously on flights in opposite directions. More accurate forecasting will, for the most part, determine the extent to which this situation can be used to advantage. Winter and summer schedule changes also reflect these wind conditions.

However, in actual airline operation a favorable wind condition leading to an early arrival is not necessarily a pure gain either in dollar savings or in convenience to the travelling public. The high cost of gate positions and their limited number precludes free use of these facilities by early arrivals. Generally the gate positions are scheduled just as closely as the aircraft they serve. Hence, an early arrival may lead to ramp congestion and on-the-spot revision of the gate scheduling. It may also result in a costly chain effect extending to maintenance, connections for other flights, and to many other operational aspects. An early arriving aircraft must then either be held in the air, which is impractical for the turbojet, or must be held elsewhere on the field until its scheduled gate is available. Either arrangement is costly. Moreover, salaries of crew members and other direct operating expenses are generally computed on the basis of established flight schedules and no savings would accrue from early arrivals. Maintenance costs are rarely reduced in scheduled operation by early arrivals. Scheduling of service checks plays an important part in this factor and a series of early arrivals may only dictate a premature maintenance period before it is legally required.

The factors listed above, based on statements of qualified airline operations personnel, explain the fact that early arrivals are not

regarded as actual dollar gains. Any savings in fuel may be more than balanced by passenger inconvenience from early arrivals, as well as by a disruption of ground servicing operations. Because of these factors, a number of air carriers instruct pilots to adhere to published schedules, to reduce cruising speeds or climb the aircraft to altitudes of lower fuel consumption in cases of expected under-schedule arrivals. A few key routes are considered "fireball routes" because of competition and the prestige value and are flown for minimum time regardless of fuel consumed.

Accordingly, favorable winds produce significant economic gains only to the extent that they offset delays on a particular flight.

However, the net effect of the gains and losses from winds could well suggest an area of potential schedule refinement since the fluctuations above and below scheduled flight times determine the tightness of the schedule and accordingly affect the cost of operation. Any solid reduction in scheduled times results in a corresponding economic benefit.

c. On-Ground Delays

Prior to take-off and after landing, aircraft are frequently delayed on the ground due to weather factors. Aircraft waiting for weather improvement or aircraft unable to unload after landing because previous aircraft, which were delayed by weather, occupy the available gates, suffer on-ground delays which result in direct and indirect dollar losses. Among the direct operating costs are stewardess salaries and any fuel consumed during possible idling of the engines. Among the indirect costs are passenger delay time and loss of aircraft utilisation. The former items are small in comparison with lost passenger time.

Loss of aircraft utilisation due to weather delays on the ground will result in loss of revenue to the particular carrier involved but not to the industry as a whole, since it has been assumed that the passengers

will obtain transportation via another air carrier in these cases. However, an accumulation of delay time and the resulting lower aircraft utilization rates will ultimately require additional aircraft in order to meet published schedules. From this standpoint capital expenditures will be incurred as a result of the on-ground delays, but it has not been considered feasible to estimate the costs involved. Accordingly, this type of weather delay will not be included as a penalty to the air carrier industry but only to the passengers.

A one year analysis of the same trunk carrier operations was made, listing all ground delays due to weather causes. These delays were reduced to proper units of minutes delay per flight and applied to all U. S. domestic carriers.

Over 292,000 flights were recorded for this carrier both piston as well as turbojet operations for the year 1960. These figures are shown in Table 3.

The weather ground delays for all flights averaged 0.7 minutes. A total of 1.35% of all flights were delayed by weather with an average 57 minutes per each delayed flight.

Using these delay averages for projection over the entire domestic air carrier fleet, the total ground delay due to weather causes in 1960 was 46,700 hours for propeller aircraft and 4,970 hours for turbojets. Table 4, shows the projections of these hours to 1975.

d. Projected Weather Delays to 1975

The total dollar losses due to weather delays in flight and on ground, have been estimated for the period 1960/61. As discussed on page 17 no penalties to the carriers will be included for ground delays. The computations are based on the fact that such operating delays are a direct function of the total number of flight hours during that period, i.e., the time of exposure

Table 3. **Reported Weather Ground Delays 1960 from Representative Domestic Air Carrier**

Month	Total	% Delayed	Total Delays	Average Minutes/Delay	Total Minutes
<u>1960</u>					
January	22,446	2.6	580	54	31,500
February	22,055	2.2	485	44	21,400
March	23,537	2.5	585	55	32,000
April	23,795	.7	166	39	6,500
May	25,965	.3	78	48	3,740
June	25,801	.4	103	37	3,800
July	26,288	.7	182	43	7,800
August	26,502	.5	135	31	4,180
September	25,006	1.0	250	67	16,800
October	25,204	1.1	276	88	23,600
November	23,077	1.8	415	65	27,400
December	22,883	3.0	685	67	45,800
TOTAL	292,559	1.35 avg.	3940	57 avg.	224,520

to weather. Employing this method it is possible to arrive at an estimate of the projected losses in the 15 year period ahead, by using the number of carrier flight hours for this period.

Using FAA projections[1], the total number of hours of expected delay can be estimated for each year. From these hours, the dollar costs of air carrier weather delays have been estimated.

---

[1] "Forecasts of Air Traffic Activity, Continental U. S. 1960-1975"

Table 4. Hours of Air Carrier Ground Delay due to Weather

Hours of Delay	1960	1965	1970	1975
Turbojets	4,970	15,850	25,600	34,400
Propeller	46,730	32,950	24,700	20,400

In order to assess these dollar costs, the direct operating costs as well as passenger time losses must be taken into account. In projecting the direct operating costs per hour, certain estimates are made for the costs of crew salaries, maintenance, insurance, fuel, flight depreciation, and the changes expected in these factors by 1975. These estimates are based on official figures published by the CAB[1]. A straight line projection is used for the period 1960 to 1975 to arrive at the costs for each five year interval. The following table shows these projections:

Table 5. Estimated Total Hourly Operating Costs Through 1975 Air Carriers Turbojets and Propeller Aircraft (From CAB Form 41, Summary, Calendar Year 1960)

Direct Operating Cost per Hour	1960	1965	1970	1975
A. Turbojets				
Crew	$85	$85	$85	$85
Maintenance	280	258	232	210
Insurance	150	147	144	140
Fuel	225	225	225	225
Depreciation	220	167	114	60
SUB TOTAL	960	880	800	720
B. Propeller A/C	320	315	310	305
C. Combined Carrier Aircraft (Weight Acc. to Flying Hours)	375	500	570	578

[1] "CAB Form 41 Calendar Year 1960"

Table 6. Projected Dollar Losses Due to Air Carrier Delays 1960-75

A. Operating Losses, In-Flight Delays Caused by Weather

ITEM	1960	1965	1970	1975
Turbojets				
Number of flight hours, millions[1]	0.39	1.23	1.99	2.67
Hours of in-flight delay	1956	6180	10,000	13,400
Cost per hour[2]	$755.	$692.	$629.	$566.
Total Operating Costs of In-flight Delays (Turbojets) ($ Millions)	$1.47	$4.28	$6.29	$7.59
Propeller Aircraft				
Number of flight hours, millions[1]	3.61	2.50	1.79	1.40
Hours of in-flight delay	28,660	19,900	14,200	11,000
Cost per hour[3]	$252	$248	$244	$240
Total Operating Costs of In-flight Delays, Propeller Aircraft	$7.22	$4.95	$3.47	$2.64
I. Total Costs, Turbojets and Propellers ($ Millions)	$8.69	$9.23	$9.76	$10.23

[1] Ref: "Forecasts of Air Traffic Activity in the Continental U.S.: 1960-1975"

[2] See Table 2

[3] See Table 2

2. Passenger Time Lost Due to Delays

In-flight and on-ground delays due to weather involve direct and indirect costs to the air carriers. They also involve lost time on the part of the passengers. Later-than-scheduled arrivals at the destination terminal constitute a definite time penalty to the passengers, and when the average value of a passenger hour is known, this penalty can be expressed in dollars.

In addition to the direct delay time, missed connections as a result of late arrivals can lead to further scheduling delays or even passenger layovers. The total annual losses of passenger time due to primary delays can be computed directly from the total hours of airplane delays, average passenger load factors, and dollar value per passenger hour.

The secondary losses would require an extensive investigation into the scheduling system of our domestic airlines, compiling number of missed connections and passenger layovers due to weather delays at all major terminals, the distribution of trip length, changes of airplane, and destinations of the traveling public. Such an investigation is beyond the scope of this study. Accordingly, this factor has not been included inthese estimates.

In order to compute the value of lost passenger time from air carrier delays due to weather, the follow. g discussion of the dollar value of a passenger hour is presented.

a. Cost Per Passenger Hour

An estimate of the cost per passenger hour caused by a delay in air carrier travel must take into account a variety of factors, such as range of passengers' incomes and reasons for travel (business or personal). The values which airline passengers place on their time would vary greatly. The business or professional man would view a delay as more costly than would a retired person traveling for personal reasons. Despite the wide range of values, the fact remains that flight delays represent an economic loss to passengers.

To assess the relevant factors would involve an actual survey of a representative sample of air passengers. We have taken the following approach to the problem based on a study by the Port of New York Authority[1].

- The median family income of the sample of air passengers was $11,400 in 1956[2]. Adjusting this figure for an increase in annual income of 2 1/2% per year we arrive at a 1960 income of approximately $13,000.

- The value of a typical air passenger's time, based on 2000 work-hours per year, was $6.50 per hour in 1960[3].

Personal income is a reasonable estimate of the value placed by an individual on his own time or by an employer on an employee's time. The employer values his employee at something more than his salary to justify hiring him. Each man-hour is therefore worth at least $6.50 in an alternative use.

---

[1] "New York's Domestic Air Travelers", Port of New York Authority, Aviation Department, October 1957.

[2] In the original - 1956 survey, 50% of the passengers were found to have family income exceeding $11,400, while the family income of 25% of the passengers exceeded $20,000. A very large income (say $150,000) in the sample would not change the median value of $11,400. We know that very high income people do fly and the value of their time is relevant to this study. Hence, the median income ($11,400) understates the average value of a passenger's time.

[3] In this estimate, we have made no adjustment for differences between value of men's and women's leisure time. Nor have we attempted to separate out property income from salaries and wages, or to determine the extent to which more than one person contributes to the family income. These factors suggest that family income tends to overstate the value of an air passenger's time. However, in our judgment, $6.50 per hour is a useful working compromise to reflect the foregoing considerations.

Personal income understates the value of a person's time during business hours and may overstate it for other occasions.

An estimate of the value of leisure time versus working time depends primarily on the individual's assessment of leisure. People do adjust their working and leisure time so that an hour is roughly equal in value as additional work time or additional leisure time. The value of an hour of work is therefore a reasonable approximation of the value of an hour's delay whether or not the passenger is engaged in business flying. In projecting hourly values over the 15 year period ahead, the 1960 salary of $13,000 has been adjusted for an annual increase of 2 1/2%. Thus, the hourly figures for 1965, 1970 and 1975 become $7.35, $8.50 and $9.40 respectively.

b. Cost of Passenger Delay

The total hours of airplane delay due to weather factors were computed in the previous section. They were grouped by type of equipment, namely turbojet and propeller-driven aircraft. With the average number of passengers per airplane, or the load factor, known, the total passenger hours of delay can be calculated and the dollar cost evaluated. Time-weighted average numbers of passengers per aircraft type have been computed for the period July 1960 to June 1961, from CAB data on Form 41. These show 71 passengers per turbojet and 34 passengers per propeller aircraft. Load factors have not changed materially in the past several years, and there is no firm basis for predicting any upward or downward trend in passenger load factors. Therefore our projections of lost passenger time are based on constant load factor values for the period to 1975. Table 7.

3. Maintenance and Ground Support

Maintenance and ground support weather penalties are sizeable in the operation of an air carrier fleet. Some of the costs are concealed in the aircraft schedules, which contain expensive pads to allow the maintenance program to conform to legal and safety requirements and still produce

Table 7. Cost of Passenger Time Lost due to Air Carrier Delays Caused by Weather

A. TURBOJETS				
Year	1960	1965	1970	1975
Hours of in-flight delays	1956	6,180	10,000	13,400
Hours of ground delay	4970	15,850	25,600	34,400
Total hours of airplane delay	6926	22,030	35,600	57,800
Average number of passengers per airplane	71	71	71	71
Total passenger hours of delay	492,000	1,560,000	2,520,000	4,100,000
B. PROPELLER AIRCRAFT				
Hours of in-flight delay	28,660	19,900	14,200	11,000
Hours of ground delay	46,730	32,950	24,700	20,400
Total hours of airplane delay	75,396	52,850	38,900	31,400
Average number of passengers per airplane	34	34	34	34
Total passenger hours of delay	2,570,000	1,800,000	1,320,000	1,042,000
C. TOTAL PASSENGER HOURS, JET AND PROPELLER	3,062,000	3,360,000	3,840,000	5,142,000
Value of passenger time per hour	$6.50	$7.35	$8.50	$9.40
Total Dollar Value (Millions)	$19.90	$24.69	$32.64	$48.34

an acceptable performance. Other costs are direct and can be more easily measured. The methods for arriving at such penalties are rather complex, due to the many variables involved, and the restrictions placed on the maintenance schedule by such factors as passenger schedule demands, location of spare parts, location of ground support equipment and the location of ground support personnel. The problem of ground support equipment and personnel is considered parallel to that of pure maintenance and often the two are intermingled. Basically, the effect of weather is the same on both activities.

In the broad picture, weather irregularities or delays must be compensated for by the purchase of new equipment over and above that ordinarily required for operations, and personnel requirements are also increased, either in the form of overtime for regular personnel or by the addition of more personnel. Personnel and equipment are also closely related. Lack of personnel can be balanced by additional equipment and, conversely, additional personnel may be used in the operation of existing equipment to accomplish the same result.

A logical approach to the study of this penalty is to compare the official FAA inspection requirements specifying the maximum airplane operating hours between checks with the actual inspection periods used by the air-carriers. The FAA requires certain service checks on the airplane to be performed after a fixed number of hours of flying. These hours are established by regulation for the various types of service and maintenance checks and for different aircraft categories. However, if the carriers were to schedule the utilization of equipment to the maximum extent of this legal period, the aircraft, because of unforeseen ATC, weather and other delays, would frequently have to be taken out of the closely planned schedule. The effect of weather interruptions on fleet utilization can be seen from Figure 4,

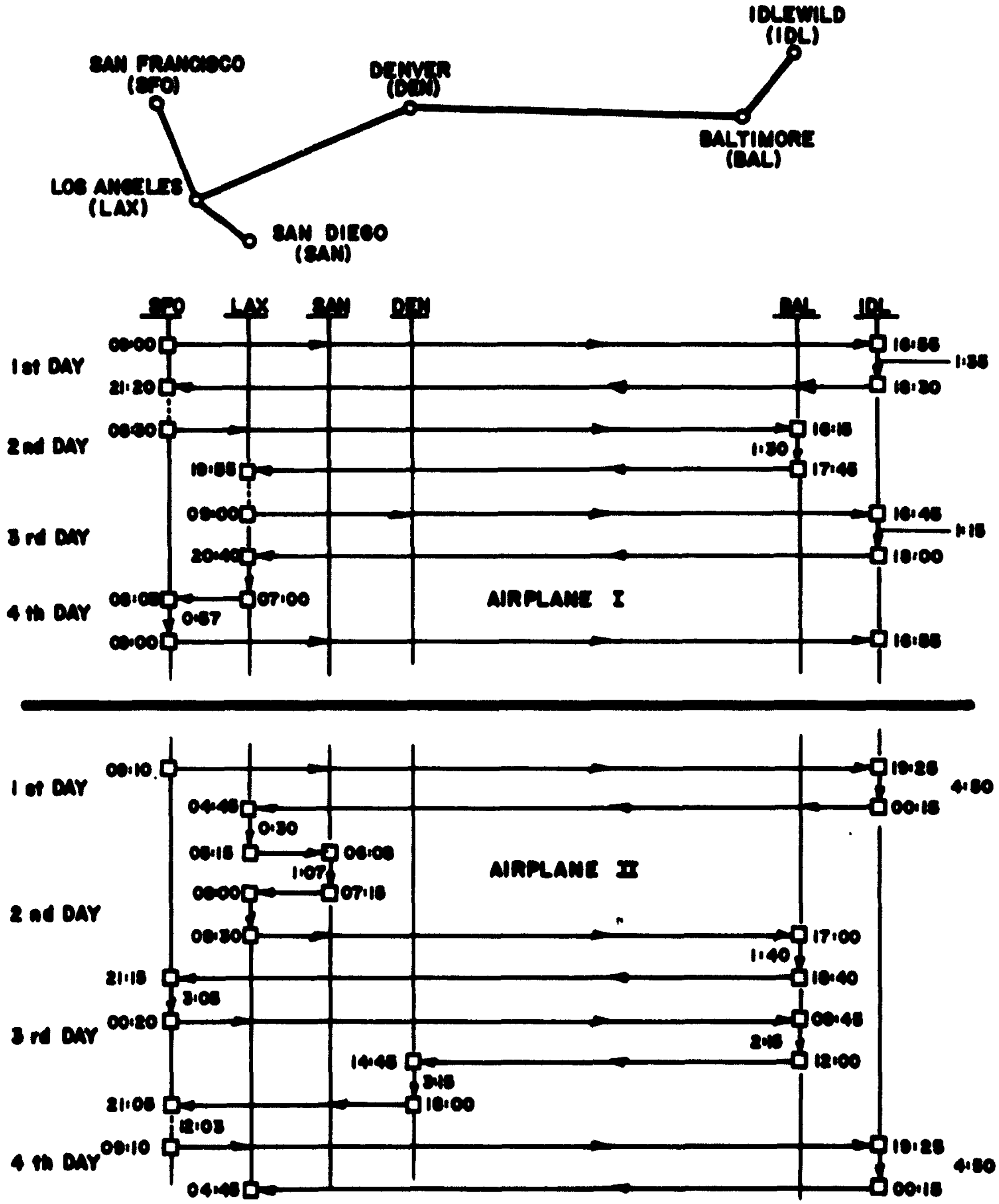

FIGURE 4. TYPICAL AIRCRAFT MAINTENANCE SCHEDULE AIRCRAFT TYPE: DC-8

showing two typical aircraft maintenance schdules for a four day period. Any deviation from the planned schedule as shown will require a complete change of plan, with a resulting loss of utilization of an aircraft.

Primarily because of these weather delays, which occur the year around, but show a greater frequency in the winter months, carriers do not fly their equipment to the maximum legal period between service checks. Instead they schedule these checks some 6 to 50% under the legally required flight time limitations. Thus, service checks are performed more frequently than required.

Some schedule "pads" are included in the scheduled turn-around times. As a typical example, the turn-around time for a trans-continental jet could be 45 minutes, according to estimates by carrier personnel. In this time interval, debarkation and embarkation of passengers can be accomplished, cargo and luggage can be handled and the aircraft can be serviced and refueled. However, to allow for ATC and weather delays, the time allotted for turn-around is usually twice this amount.

To illustrate the excess of service checks due to weather uncertainties, the Tables 8, 9, and 10 show typical monthly figures stating the required maximum operating hours for three types of service checks and the actual hours flown between checks. The tables show maintenance schedules of three different types of aircraft; they represent actual data of a major trunk carrier.

Service Check A, which must be performed after a maximum of 60 operating hours for propeller aircraft and 65 operating hours for turbojets, is performed after about 80% of the legally allotted time, while Service Check B is performed within 90% of the legal period for propeller aircraft and about 80% for turbojet aircraft. These increases in service checks are considered typical for the carrier industry.

Table 8. Required and Actual Frequency of Service Checks A and B. Typical Domestic Trunk Carrier

Aircraft Type: LOCKHEED 749/A

Month	1960				1961			
	FAA Limits		Avg. Attained		FAA Limits		Avg. Attained	
	SS-A	SS-B	SS-A	SS-B	SS-A	SS-B	SS-A	SS-B
January	60	180	47	147	60	180	52	163
February	60	180	48	164	60	180	53	162
					SS (both service checks combined)		SS	
March	60	180	46	166	120		113	
April	60	180	50	165	120		106	
May	60	180	48	165	120		100	
June	60	180	50	165	120		103	
July	60	180	50	160	120		106	
August	60	180	50	160	120		104	
September	60	180	50	160	120		108	
October	60	180	50	157	130		109	
November	60	180	51	158	130		115	
December	60	180	48	160	130		109	
			Avg. 82% of FAA Limits	Avg. 90% of FAA Limits			Avg. 92% of FAA Limits	

Table 9. Required and Actual Frequency of Service Checks A and B. Typical Domestic Trunk Carrier

Aircraft Type: LOCKHEED 1049G

	1960				1961			
Month	FAA Limits		Avg. Attained		FAA Limits		Avg. Attained	
	SS-A	SS-B	SS-A	SS-B	SS-A	SS-B	SS-A	SS-B
January	60	120	46	106	60	120	51	106
February	60	120	47	105	60	120	51	103
					SS		SS	
March	60	120	48	095	120		108	
April	60	120	49	107	120		109	
May	60	120	47	102	120		104	
June	60	120	47	103	120		105	
July	60	120	48	104	120		106	
August	60	120	48	102	120		106	
September	60	120	49	103	120		105	
October	60	120	48	104	130		106	
November	60	120	50	99	130		117	
December	60	120	49	102	130		118	
			Average: 80% of FAA Limits	87%			Average: 88% of FAA Limits	

Table 10. Required and Actual Frequency of Service Checks A and B. Typical Domestic Trunk Carrier

Aircraft Type: BOEING 707/121

Month	1960				1961	
	FAA Limits		Avg. Attained		FAA Limits	Avg. Attained
	SS-A	SS-B	SS-A	SS-B	SS	SS
January	65	130	53	91	120	103
February	65	130	46	95	120	103
March	65	130	51	103	120	106
April	65	130	50	97	120	104
May	65	130	53	106	120	102
June	65	130	52	108	120	99
July	65	130	50	105	120	100
August	65	130	51	102	120	102
September	65	130	53	103	120	98
October	65	130	51	102	130	104
November	65	130	53	107	130	110
December	65	130	52	106	130	111
			Average: 80% of FAA Limits	Average: 78% of FAA Limits		Average: 85% of FAA Limits

In order to obtain a representative sampling on maintenance penalties due to weather factors, three major trunk carriers were contacted. There was a marked similarity in the results. The spacing of the actual maintenance schedule periods varied slightly with the individual operator. However the basic criteria were the same in all cases.

FAA inspection and maintenance check requirements are constantly being upgraded and revised to reflect the increased operating experience of individual carriers. This is shown in Tables 8 and 9 where in March 1961 Service Checks A and B for this particular carrier and aircraft type were combined into one check having a limit of 120 hours between inspections.

There are approximately five types of checks, each stipulating a different maximum flight time. Of these five types only three are influenced by weather to a marked degree. They are listed as checks 2, 3, and 4 in the attached Table 11. Column three of the table shows the total number of checks performed in each category by these three major carriers in 1960. Total man-hours required for these checks are listed in column five.

The smallest maintenance period appreciably affected by weather irregularities is the layover check required every other day. To avoid exceeding this legal limit and to maintain a desirable standard of schedule performance the carriers perform this check daily. Of this 100% increase, 50% is considered by air carrier maintenance personnel to be attributable to weather causes.

The data for Check No. 3 for example indicate that 65 flight hours is the required legal limit. Man hours required to perform this check vary from 7 to 63 depending on type of equipment. As shown in Column 7, for the turbojets 22% of the maintenance man-hours are due to weather, and for propeller aircraft from 9% to 12% of the man-hours.

Table 11. Maintenance Checks Required and Additional Man-Hours Due to Weather Uncertainties, 1960

Type Aircraft	Hrs. Required Per Check	Total Flying Hours	Minimum Number Checks	Man Hours per Check	Total Man Hours	% Increase Due to Weather	Man Hrs. Due to Weather
A. Turbojet (DC-8)		121,000					
Check 2	48		2500	4	10,000	50%	5000
Check 3	65		1880	20	37,500	22%	8250
Check 4	320		380	470	180,000	9%	16,200
B. Turbojet (B-707, B-720, CVR 880)		244,000					
Check 2	48		5100	24	122,000	50%	61,000
Check 3	65		3750	63	236,000	22%	51,900
Check 4	320		760	626	470,000	9%	42,500
C. Prop. (Electra)		259,000					
Check 2	48		5200	16	84,000	50%	42,000
Check 3	65		4000	27	108,000	9%	9,750
Check 4	350		750	289	218,000	6%	13,100
D. Prop. (DC-6, 7, L-1049G)		2,000,000					
Check 2	48		41,500	6	249,000	50%	124,000
Check 3	65		31,000	11	340,000	12%	40,800
Check 4	350		5700	146	830,000	7.5%	62,000
E. Prop. (CVR 340, L749)		950,000					
Check 2	48		19,600	5	100,000	50%	50,000
Check 3	65		14,500	7	101,000	10%	10,100
Check 4	350		2,700	125	335,000	6%	20,100
TOTAL EXCESS MAN HOURS DUE TO WEATHER UNCERTAINTIES -							556,700

Check No. 4 required 9% additional maintenance inspections due to weather uncertainties for the turbojets, and from 6% to 7.5% for the propeller aircraft.

In summarizing, an annual total of 556,700 man-hours is estimated to be the excess maintenance performed by the three sampled air carriers.

In order to arrive at the weather-induced increment of maintenance costs, the added man-hours are priced at an average regular rate of $7.00 per hour[1] or a total of $3,900,000.00 for the year 1960. If this figure is compared with the total air carrier expenditures on maintenance personnel during 1960, ($181,773,614) the excess cost factor due to weather uncertainties is 2.18%[2].

It is of interest that estimates of increase in maintenance expenditures due to weather by qualified air carrier personnel from the three major carriers were: 1.5 to 2.0%, 4 to 5%, and 1.5 to 2.0% respectively, for the weather increment. This is in line with the value of 2.18% estimated above.

This weather factor, when applied to the total air carrier maintenance and ground support personnel expenditures for 1960[3], gives an amount of $8,280,000 for added personnel costs. For the ground support equipment[4], application of the same weather factor results in a value of $455,000, which

[1]This hourly figure includes direct labor and company overhead. It constitutes an average value from three major trunk carriers.

[2]Ref: ATA "Facts and Figures about Air Transportation", 1960.

[3]Ref: Cited 2

[4]Ref: Cited 2-3, From the above Ref. Personnel, Service, and Maintenance $380,442,181.00 Aircraft Support Equipment, 1960, $20,956,000.00

represents the estimated additional support equipment by weather uncertainties[1-2]

Added personnel costs due to weather*	$8,280,000
Added equipment costs due to weather	455,000
Total excess costs, 1960:	$8,735,000

Projected Maintenance Weather Penalties 1960-1975

In projecting the weather caused maintenance costs through 1975, the total maintenance penalty due to weather, $8,735,000.00, for the year 1960 has been adjusted for the forecast flight activity (maintenance is a direct function of flight activity) and hourly maintenance costs to obtain the total projected maintenance penalties for that period.

---

[1]According to statement by a major trunk carrier, costs of ground equipment and services increase by 20% in the winter. It is felt that more accurate forecasts can result in substantial cost savings. For example, instead of "snow", they would like "wet snow", "dry snow", "freezing rain", also the amount of snow fall. Lack of accurate forecasts of this type costs them on the order of $200,000-$300,000 a year minimum.

[2]Typical example of maintenance delay due to weather information. A major maintenance base experienced low visibility and icy runways for three days. There was no snow removal equipment available. Therefore the carrier could not bring in a B-707 for scheduled engine change. It had to make the engine change in Los Angeles on overtime. Maintenance base personnel expecting the B-707 were kept idle. In addition, the removed engine was shipped by truck from Los Angeles to the maintenance base and the repaired engine was shipped back to Los Angeles for standby. The round trip took eight days, during which time the engine was out of service.

Table 12 shows projected flying hours and weighted hourly maintenance costs (28% of weighted hourly direct operating costs)[1], from which the total maintenance penalty has been estimated.

Table 12. Maintenance Weather Penalties Through 1975

	1960	1965	1970	1975
Total flying hours (1000)[2]	3865	3728	3790	4070
Weighted hourly operating costs	\$375	\$500	\$570	\$578
Weighted hourly maintenance costs	\$104	\$140	\$159	\$161
Weather Penalty (2. 18% of total maintenance costs)	\$8.74	\$11.26	\$13.05	\$14.20

[1] Appendix C

[2] FAA Forecast of Annual Flight Activity in CONUS 1960-1975, FAA Traffic Analysis Branch

4. U. S. Mail Delays

Among the economic losses traceable to inadequate weather information to aviation are the losses involved in U. S. mail delays. They are real and tangible as far as the hours of delay are concerned. They are less tangible however when a dollar value is to be placed on the delay to a unit of mail.

Requests for estimates of such delays were directed at various regional air mail offices of the U. S. Postal Service without success. According to the Bureau of Transportation, Post Office Department, Washington,D. C., such data are not available because of the complexity of the methods of transport of U. S. Air Mail to its final destination. Another difficulty is the fact that each load of Air Mail involved in a weather disruption has a variety of ultimate destinations.

Personnel contacted at the Post Office Air Mail Centers indicated strongly that the lack of adequate weather services and forecasts had a sizeable effect on the U. S. Air Mail operations. It was also brought out that any improvement in the present weather services would result in appreciably more timely delivery.

The effects of inadequate weather service upon the operations of U. S. Air Mail were discussed specifically with personnel at the Air Mail Facility of the Los Angeles International Airport. Following are several of the typical points brought out:

- The services of the U. S. Weather Bureau are used by the Post Office Centers for air mail route planning. Moreover the Air Mail office consults with Air Carrier Flight Dispatch offices regarding weather situations as they effect the Air Mail Flights.

- Working hours of Air Mail Facility employees during normal weather are planned for an eight hour day while potential overtime of two hours per working day is allowed for as a reserve against irregular peak loads, the majority of peak loads being caused by weather disruptions.

- A severe delay in air mail is experienced in case of a diversion from Los Angeles International Airport to Ontario, California, located about 30 miles inland. This is particularly true for turbojet aircraft, especially during the winter months (Ontario Diversions, Appendix G). The delays in trucking the mail back from Ontario to Los Angeles and the added handling, requiring additional man hours, constitute an economic penalty to the Post Office. In addition, the delay in mail delivery to the community accounts for additional economic losses, although these would be difficult to assess without a representative sampling.

- In the case of helicopter mail service, such as is being provided for the Southern California area, an inaccurate weather forecast can delay the final arrival of important mail by as much as 24 hours. As an example, the case was cited where the mail is held until the scheduled departure of the mail-carrying helicopter and the flight is then cancelled because of weather. The mail may arrive fully a day late at its final destination. Had a more accurate forecast been available, the probable cancellation of the flight would have been known beforehand and the mail would have been placed on earlier surface transportation, thereby minimizing the delay.

5. **Alternate and Contingency Fuel**

Reserve fuel requirements can be grouped into: Basic FAA Reserve, Alternate Fuel, Contingency Fuel, and Pilot's Contingency Fuel. The basic FAA reserve is a safety requirement not specifically attributable to weather alone. The other three, however, are necessitated primarily by the uncertainty as to weather conditions or lack of adequate weather information.

Alternate Fuel Requirements -

The naming of an alternate airport for destination is required by Civil Air Regulations for the following conditions:

- Instrument flying conditions at destination
- Certain weather conditions at departure airport
- When an area of thunderstorms is forecast for the destination
- When destination runways are covered with snow, slush, or ice
- When only one runway is available at destination airport

One exception to the above requirement is that an alternate need not be named on an instrument flight when the destination terminal, two hours before and two hours after planned arrival, is forecast to have a ceiling of at least 1000 feet above the minimum approach altitude for that airport and at least 3 miles visibility. These alternate rules are basic safety requirements and are used to compensate for radio failures, uncertainty of weather forecasts, or the closing of the single available runway by some unforeseen contingency.

For the purpose of this study, a sampling of 3697 air carrier flights dispatched from Chicago was used. This sampling, covering the month of September, is not completely representative of the yearly average inasmuch as that period is relatively free from unfavorable flying weather. Of the total flights covered, 56% of the propeller driven aircraft and 62% of the turbojets required the naming of an alternate airport, which necessitated ferrying additional alternate fuel. Another sampling of 1,589 flights taken at Los

Angeles indicated that 66.5% of all propeller-driven flights and 63% of the turbojet flights required additional fuel for alternate requirements due to weather. In using the Chicago percentages computations indicate that a total of 8,904,700 pounds of alternate fuel were ferried on the 3,697 flights reported. (See Table A-1, Appendix).

The effect of carrying additional weight varies with type of equipment. In general, piston flights are affected to the extent that a short increment of flying time is added to the total trip duration. On turbojet flights, measurable fuel is actually consumed to ferry alternate fuel to the destination.

In calculating the turbojet penalty, the actual fuel consumed will vary with the length of flight. Computations based on data from the Douglas DC-8 turbojet manual show that from 0.27 to 0.35 pounds were consumed for every pound carried for the average length of flight in 1960. This value will decrease as the average length of the turbojet flight decreases. On this basis, the total cost of jet fuel consumed in 1960 to ferry alternate fuel was computed to be $2.2 million, see Table 14.

Projecting the added flying time due to carrying alternate fuel over the entire propeller-driven fleet in 1960, a value of 10,660 hours has been computed. Using the weighted hourly operating cost of $252 for propeller aircraft the annual penalty is estimated at $2,686,000 for the year 1960.

Turbojet, Alternate Fuel Costs (1960)	$2,200,000
Propeller Driven Fleet, Alternate Fuel Costs (1960)	2,686,000
Total	$4,886,000

Contingency Fuel Requirements (Turbojets only) -

Contingency Fuel

At time of dispatch, turbojet fuel requirements are made up of the basic FAA reserve, the planned burnout for the trip, the alternate fuel required,any holding or detour fuel, and another reserve amount known as "contingency fuel". The latter is presently in the neightborhood of 4000 pounds minimum which is automatically carried on every flight.

The use of this contingency "pad" is a safety requirement, It is clearly a cost penalty introduced for the most part by the uncertainty of weather forecasting for such parameters as optimum flying altitudes, temperatures aloft, turbulence, winds aloft, and ATC requirements.

Using the total number of turbojet flights in 1960, an average contingency fuel load of 4, 000 pounds and assuming a nationwide trip average of 0. 3 pounds of fuel burned per pound of fuel carried and a cost of 1. 5 cents per pound, the cost of carrying this contingency was $1, 800, 000 in 1960.

Pilot's Contingency Fuel

The standard contingency fuel load is sometimes increased by the pilot when weather or traffic factors appear somewhat less favorable than forecast. Examination of the operating statistics of a typi cal domestic trunk carrier shows that 92% of the pilots accept computer calculated flight plans while the remainder still prepare their own manual flight plans. Of the 92%, a little more than one fourth, or 28%, increase the 4000 lbs. contingency by an additional fuel load which averages 3500 lbs. per flight. Thus, of all the flights of this carrier 25. 8% add an average amount of 3500 lbs. each to the fuel load. This additional fuel is justified by the pilots on the grounds of lack of confidence in the weather forecasts and weather inputs into the computer (winds aloft, etc.) This practice is fairly universal among domestic carrier jet pilots.

Applying this ratio, 25.8%, to the entire domestic air carrier fleet, the cost of fuel consumed is estimated as shown in Table 13.

Table 13. Pilot Requested, Added Contingency Fuel

	1960	1965	1970	1975
Avg. length of jet flight, hours	3.7	1.23	.96	.83
Fuel consumed per lb. carried	0.3	0.25	0.23	0.22
Total Number Jet Flights (millions)	0.1	1.00	2.08	3.22
No. of flights with added reserve	25,800	258,000	535,000	825,000
Added fuel carried in lbs. (millions)	90.1	901.0	1870.0	2880.0
Fuel consumed, in lbs. (millions)	27.2	226.0	430.0	635.0
Cost of fuel consumed (millions)	$0.41	$3.40	$6.49	$9.52

Propeller-driven aircraft are less likely to require this contingency fuel pad due in part to the shorter length of flight as well as the higher experience level on this type aircraft. The contingency reserve is therefore not considered for propeller equipment.

This analysis does not consider other modifying factors, such as the economic advantage of carrying fuel through stations because of price differences in fuel at various locations. Such refinement would result in very little increase in the accuracy of the results.

Projected Alternate and Contingency Fuel Costs, Period 1960-1975

Since the reserve fuel requirements are a direct function of number of flights, it is possible to project the total costs for the 15 year period ahead, if the number of expected flights can be estimated. Based on FAA forecasts[1], and assuming no change in the aviation weather services, the projected reserve fuel costs due to weather factors are:

Table 14. Estimated Costs of Alternate and Contingency Fuel Due to Weather, 1960-1975 (In million dollars)

A. TURBOJETS

Item	1960	1965	1970	1975
No. of air carrier jet flights, in millions	.1	.996	2.083	3.218[1]
Average length of flight, hrs.	3.7	1.23	.96	.83
Fuel consumed per additional pound carried, pounds	.3	.25	.23	.22[2]
Alternate jet fuel for air carrier fleet (million pounds)	142.0	1185.0	2270.0	3450.0
Total cost of fuel consumed to carry alternate at 1.5 cents/lb. (millions)	$2.13	$17.76	$34.05	$51.75
Contingency fuel[3] carried(min. 4000 pounds per flight) (million pounds)	400	4000	8320	128880
Total cost of fuel consumed to carry contingency at 1.5 cents/lb. (million)	$1.80	$15.00	$28.71	$42.64
Pilots additional[4] contingency fuel carrier (million pounds)	90.1	901.0	1870.0	2880.0
Total cost of fuel consumed to carry pilot's contingency (millions)	$0.41	$3.40	$6.49	$9.52

Table 14. Estimated Costs of Alternate and Contingency Fuel Due to Weather, 1960-1975 (In million dollars)(Cont'd.)

B. PROPELLER DRIVEN

Item	1960	1965	1970	1975
Additional flying time required to carry alternate fuel, hours	10,660	10,660	9,070	9,100
Cost per hour	$252	$248	$244	$240
Total cost of additional flying time (millions)	$2.68	$2.64	$2.21	$2.18
C. SUM OF A AND B - TOTAL COST IN MILLION DOLLARS	$7.02	$38.80	$71.46	$106.09

[1] FAA "Forecast of Annual Flight Activity in CONUS 1960-1975"

[2] DC-8 Operating Manual

[3] The minimum noted was 4000 pounds. More than this minimum is carried on some flight operations.

[4] This is a confidence factor. Present air carrier experience indicates that 92% of all pilots accept computer flight plans, while 8% select different altitudes and/or routes. It was found, that on 28% of the 92%, or 25.6% of all flights, the captain requests an additional average of 3500 pounds per flight.

The contingency and alternate fuel pad costs represent areas of potential economic benefit to be gained by more accurate weather forecasting, shorter forecasting periods and a greater confidence factor on the part of the airline pilot and dispatcher. The turbojet operation is especially penalized by the added costs of ferrying reserve fuel, and the greatly increasing number of jet flights in the 15 year period ahead will result in considerable cost to the air carriers, unless necessary improvements in weather forecasting are made. See Figure 5.

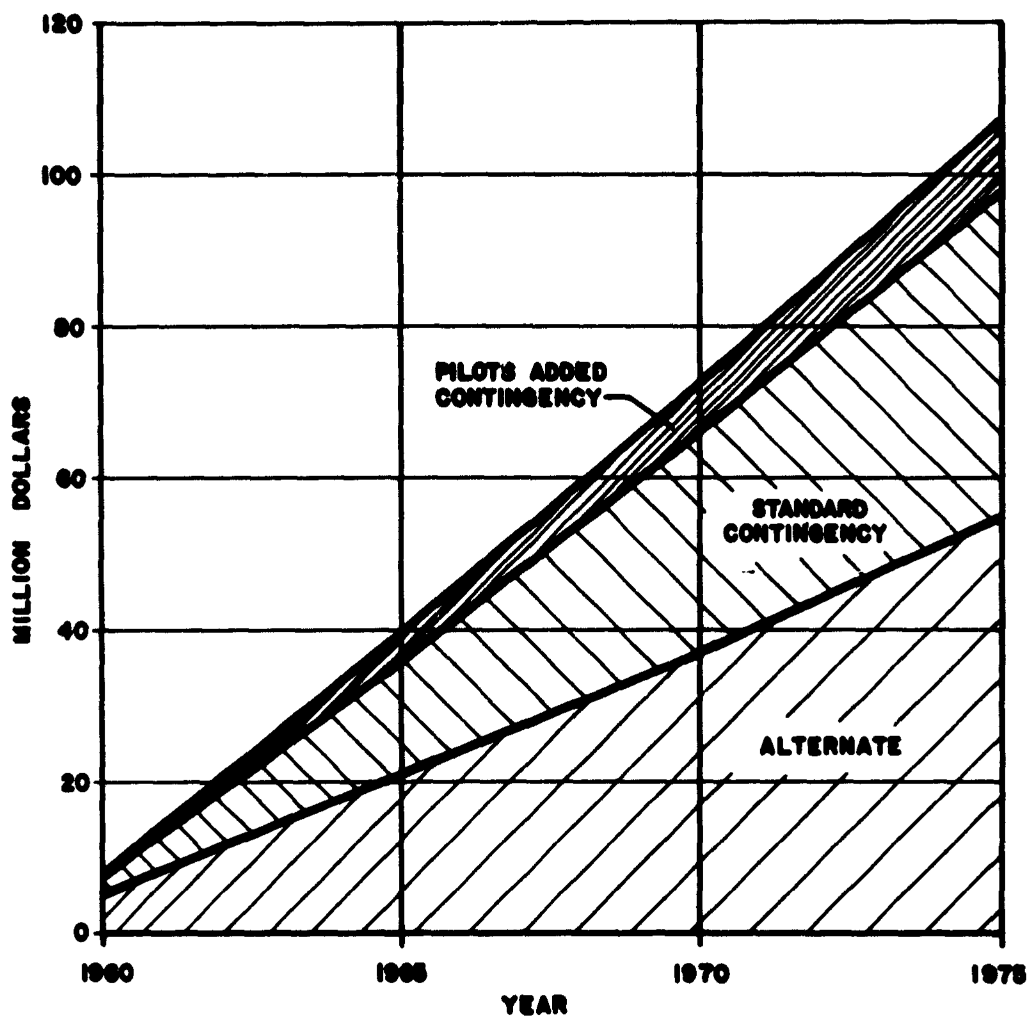

FIGURE 5 COSTS OF RESERVE FUEL REQUIREMENTS OF AIR CARRIERS DUE TO WEATHER UNCERTAINTIES

6. <u>Cancellations</u>

a. Number of Cancellations Due to Weather

The total number of revenue passenger miles flown per month by the trunk and local service carriers are plotted on the attached graphs. Figures 6 and 7. It can be seen that there is a marked seasonal variation in both curves with a maximum in August and a minimum in February. The difference between the maximum and minimum in both cases is on the order of 20% of the total number of revenue passenger miles flown. The real difference is no doubt somewhat less, although still appreciable, due to the fact that February has three less days than August.

The fact that weather factors play an important part in determining this seasonal variation is obvious. However, this effect cannot be isolated from other factors such as the habits of the traveling public, summer vacation periods, etc., using this data.

A different type of data, available from Civil Aeronautics Board publications, is useful for this purpose. This is the actual aircraft miles flown expressed as a percentage of the aircraft miles scheduled, data for which is available for the years 1952-1960. The data are combined for both domestic trunk and local service carriers. The monthly averages are given in the table below and plotted on the attached graph, See Figure 9.

	Scheduled Aircraft Miles Actually Flown as a Percent of Scheduled Aircraft Miles, 1952-1960		Percent of Scheduled Mileage Cancelled Due to Weather Factors
January	94.72		3.79
February	95.83		2.68
March	96.29		2.22
April	98.07		0.44
May	98.26		0.25
June	98.18		0.33
July	98.53		0.00
August	98.49	98.51	0.00
September	98.50		0.00
October	98.23		0.28
November	96.97		1.54
December	95.78		2.73
		Annual Average	1.19%

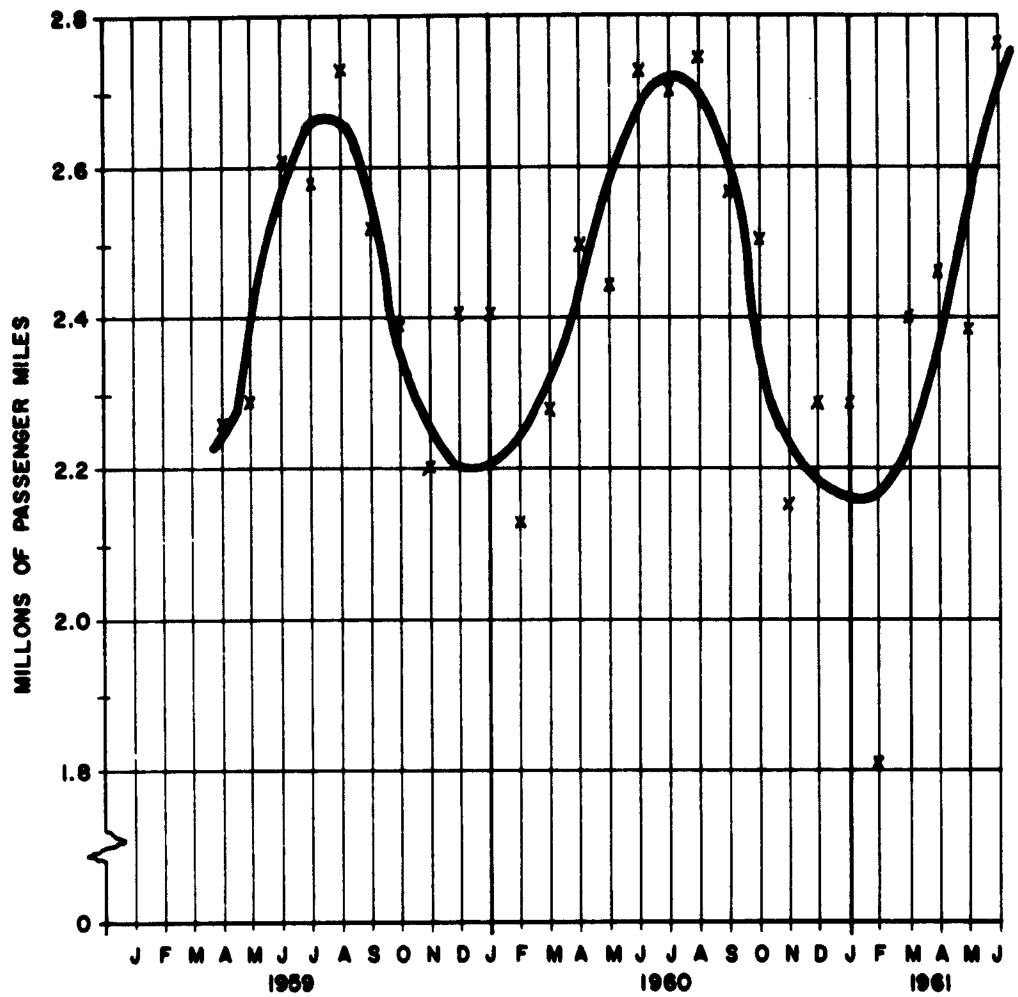

FIG. 6. REVENUE PASSENGER MILES
DOMESTIC TRUNK CARRIERS

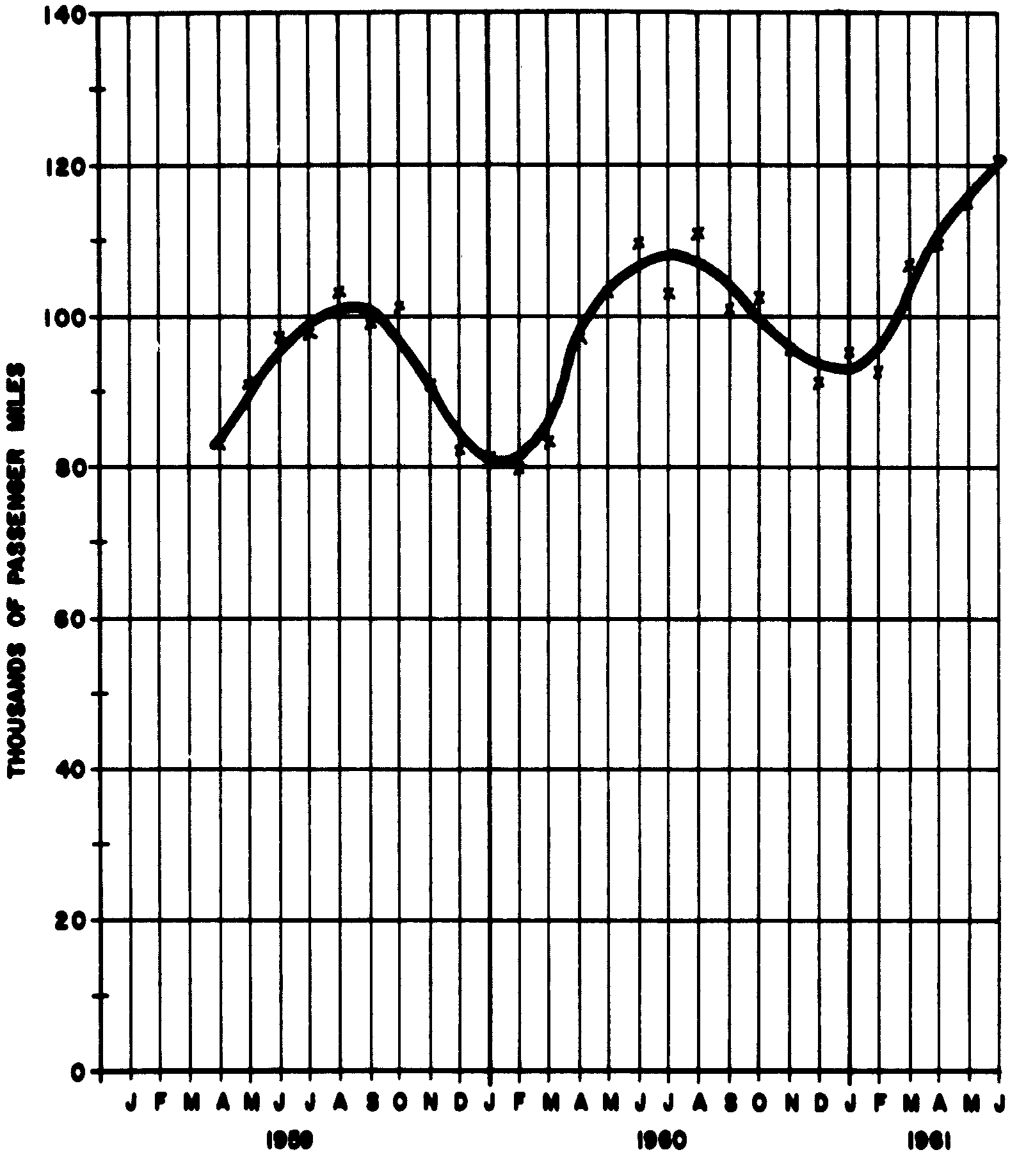

FIG. 7. REVENUE PASSENGER MILES
LOCAL SERVICE CARRIERS

It can be seen that the percentage of scheduled aircraft miles actually flown is at a relatively high, constant level during the three good weather months of July, August and September (98.51%), descends through the autumn to a minimum in January (94.72%), and improves steadily through the spring back to the summer high level.

Flight cancellations are due essentially to two main causes: weather factors and mechanical failures. In the three good weather months, weather factors are largely non-existent, while mechanical failures are fairly constant throughout the year. Thus, the difference between the good weather performance and that of the remaining months can be attributed to weather factors only, Figure 8. Such an estimate, if anything, is conservative, since there are a certain number of weather caused cancellations in the summer months.

If these differences are tabulated, a maximum of cancellations is found for the month of January, amounting to 3.79% of the scheduled aircraft mileage, and a minimum of zero during the months of July, August and September. This results in an annual average of 1.19%. See Figure 9.

The yearly averages of percentage of scheduled aircraft miles actually flown are presented below for the years 1952-1959. It can be seen that the percentage has remained remarkably constant over the entire period, no trends being apparent. A projection of no essential change can be made for the future, barring major improvements in air traffic control, mechanical reliability and/or aviation weather service.

Scheduled Aircraft Miles Actually Flown as a Percent of Scheduled Aircraft Miles

1952	97.07%
1953	97.44%
1954	97.81%
1955	97.98%
1956	96.65%
1957	97.43%
1958	97.37%
1959	97.33%

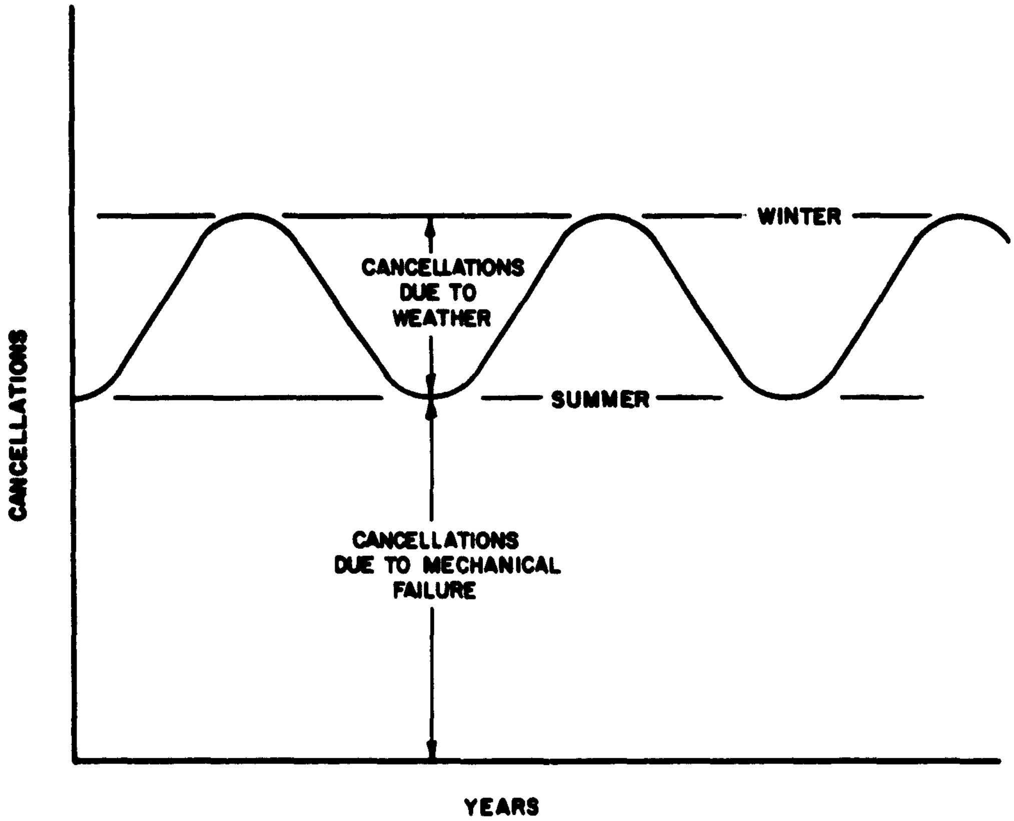

FIGURE 8. WEATHER CAUSED CANCELLATIONS

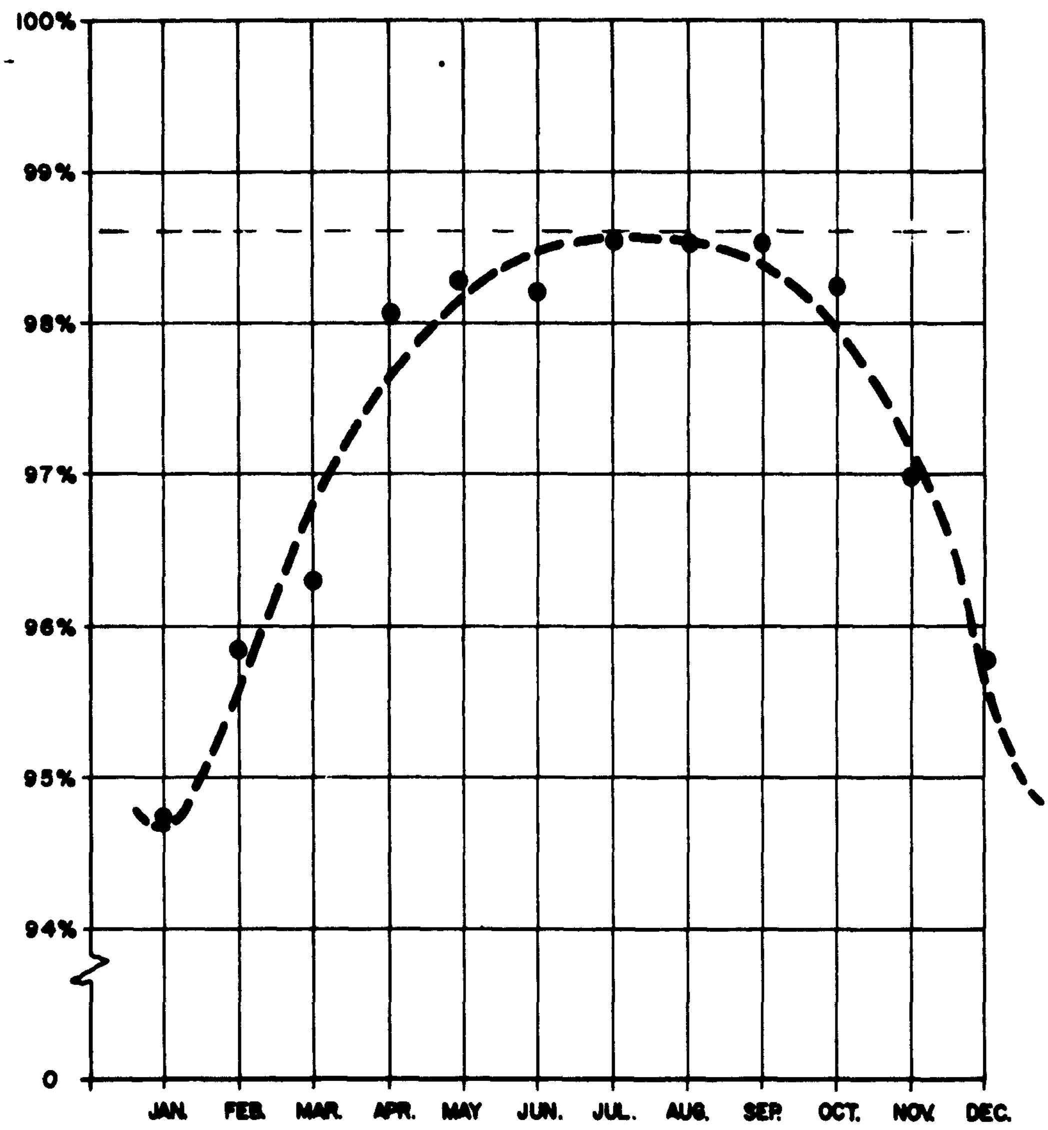

FIG. 9. AIRCRAFT MILES FLOWN AS PERCENT OF AIRCRAFT MILES SCHEDULED
(AVERAGES 1952-1960)

b. Interrupted Trip Expense

The cost to the airlines of taking care of passengers whose trips are interrupted by weather, mechanicals, etc., is reported to the CAB on Form 41 quarterly. The carriers are instructed to record "expenses allowed or paid for the care and serving of passengers because of unscheduled interrupted passenger journeys. Cost to the air carrier of forwarding passengers by surface common carrier, or ticket refunds, shall not be charged to this account...."

The cost incurred by six representative airlines, three trunk carriers and three local service carriers, chosen so as to give a geographical distribution for the years 1959, 1960 and the first half of 1961, are given in Table 15. To permit comparison between airlines these figures have been divided by revenue passenger miles flown for each quarter and the results presented in Table 16.

The average costs to the three trunk carriers and the three local service carriers are plotted in the attached graphs. A seasonal trend with maximum costs occurring in the winter months and minimum costs in the summer months is evident. We shall assume that these averages can be applied to the whole industry.

The extent to which interrupted trip expense may be attributed to weather can be estimated by taking the difference between the two winter quarters, when expenses are high, and the two summer quarters, when they are relatively low. This assumes that diversions and cancellations in the summer quarters, the 2nd and 3rd, are due to non-weather factors, principally mechanical failures, and that the excess in the winter quarters, the 4th and 1st, over this figure represents the effect of adverse weather since non-weather factors should remain essentially constant throughout the year. If anything, this estimate is conservative since there are a certain number of cancellations and diversions due to weather causes in the summer months.

Table 15. Interrupted Trip Expense in Dollars

Quarter Ending

Carrier	Mar 31	Jun 30	Sept 30	Dec 31	Year
		1959			
United-Domestic	176,249	56,769	68,834	146,055	447,907
Eastern-Domestic	237,126	158,433	153,400	251,848	800,807
Western-Domestic	29,900	14,676	22,966	45,602	113,144
Mohawk	5,434	2,912	3,349	5,278	16,973
North Central	6,957	7,466	5,150	14,557	34,130
West Coast	1,945	1,476	2,023	8,747	14,191
		1960			
United-Domestic	197,136	135,249	128,101	212,690	673,176
Eastern-Domestic	353,256	246,714	179,037	180,100	959,107
Western-Domestic	45,390	19,068	25,731	31,641	121,830
Mohawk	7,296	5,599	6,454	6,501	25,850
North Central	2,410	11,044	6,936	8,985	29,375
West Coast	5,336	3,377	3,573	5,828	18,114
		1961			
United-Domestic	334,188	153,163			
Eastern-Domestic	280,156	124,172			
Western-Domestic	26,193	17,929			
Mohawk	7,528	7,140			
North Central	12,455	9,288			
West Coast	4,832	2,094			

Table 16. Interrupted Trip Expense in Cents Per 1000 Revenue Passenger Miles

	United	Eastern	Western	Mohawk	North Central	West Coast
1959						
1st Quarter	15.4	22.4	15.9	23.1	23.5	14.2
2nd Quarter	4.4	13.9	7.3	11.2	19.3	9.2
3rd Quarter	4.5	13.3	8.7	11.8	10.6	9.7
4th Quarter	13.8	22.9	18.6	17.9	36.6	41.0
1960						
1st Quarter	19.2	31.4	18.7	34.2	6.4	24.8
2nd Quarter	9.7	25.1	8.2	18.1	25.0	13.8
3rd Quarter	8.1	17.8	9.7	19.2	14.1	13.6
4th Quarter	14.1	19.1	14.9	19.4	22.0	28.5
1961						
1st Quarter	24.1	28.7	18.4	23.8	28.9	21.1
2nd Quarter	8.8	11.9	9.1	18.0	19.7	8.9

	Average of Trunks	Average of Locals	Average of Total
1959			
1st Quarter	17.9	20.3	19.1
2nd Quarter	9.2	13.2	11.2
3rd Quarter	8.8	10.7	9.8
4th Quarter	18.4	31.8	25.1
1960			
1st Quarter	23.1	21.8	22.5
2nd Quarter	14.3	19.0	16.7
3rd Quarter	11.9	15.6	13.8
4th Quarter	16.2	23.3	19.8
1961			
1st Quarter	23.7	24.6	24.2
2nd Quarter	9.9	15.5	12.7

We will use the interrupted trip expenses figure for the domestic trunk carriers, since these represent the great majority of the revenue passenger miles flown and are less than the comparative expenses for the local service carriers. From the table for interrupted trip expense we find that the average for the five summer quarters (2nd and 3rd) is 10.8 cents per 1000 revenue passenger miles and the corresponding average for the five winter quarters (1st and 4th) is 19.9 cents. The difference is 9.1 cents per 1000 revenue passenger miles which will be used in projecting this type of expense into the future, See Figure 10.

In order to compute the annual costs to the airlines of interrupted trips in future years, we will use the passenger traffic projections given in the report of Project Horizon[1], which are as follows:

- 1960- 30 billion revenue passenger miles
- 1965 - 43 billion revenue passenger miles
- 1970 - 57 billion revenue passenger miles

In addition, the Traffic Analysis Branch, Systems Engineering Division, Aviation Research and Development Service, FAA, estimates an annual figure of 73 billion revenue passenger miles by 1975. We will use straight-line interpolation between the four points to obtain annual figures.

One final step remains before a projection can be made. The curves of revenue passenger miles flown, Figures 6 and 7 show that there is a marked seasonal variation in travel with a maximum in the summer months and a minimum in the winter months. The distribution during fiscal years 1960 and 1961 was 54% in the two summer quarters and 46% in the two winter quarters. Accordingly we will multiply the forecast revenue passenger miles for the entire fiscal year by a factor of 46% in order to obtain a value for the two winter quarters. The results of the computation are given in the following table:

---

[1] Report of the Task Force on National Aviation Goals, September 1961.

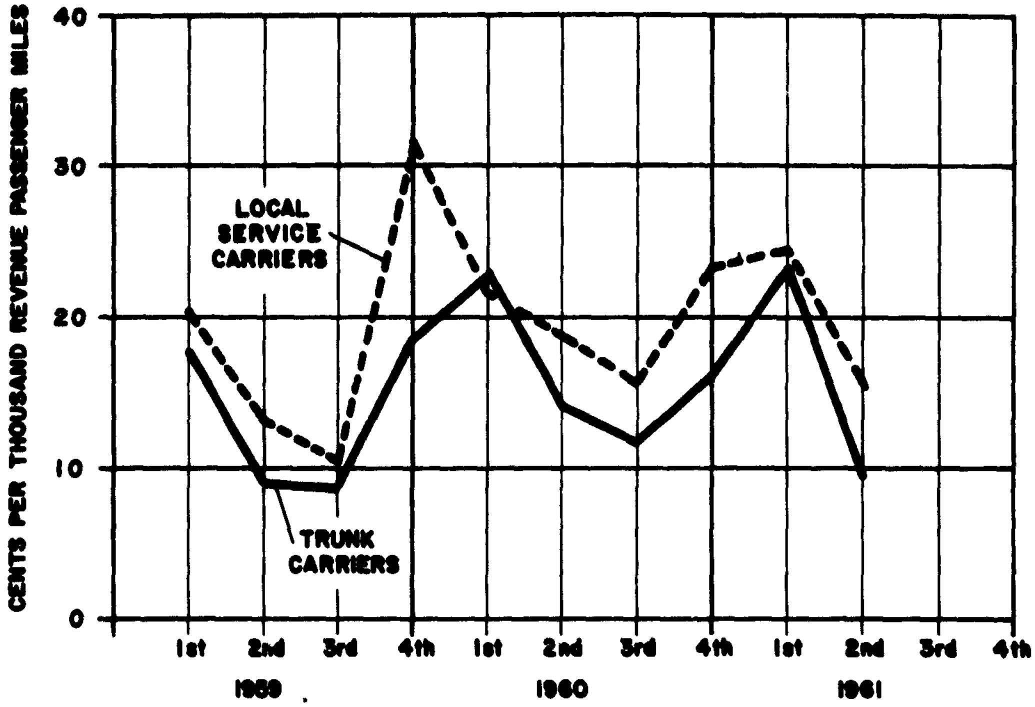

FIG. 10. INTERRUPTED TRIP EXPENSE, CENTS PER THOUSAND REVENUE PASSENGER MILES.

Table 17. Interrupted Trip Expense

Fiscal Year	Forecast Revenue Passenger Miles (Billions)	Revenue Passenger Miles Winter Quarters (46% of Annual)	Forecast Interrupted Trip Expense Due to Weather
1960	30.0	13.8	$1,256,000
1961	32.6	15.0	$1,365,000
1962	35.2	16.2	$1,474,000
1963	37.8	17.4	$1,583,000
1964	40.4	18.6	$1,693,000
1965	43.0	19.8	$1,802,000
1966	45.8	21.1	$1,920,000
1967	48.6	22.4	$2,038,000
1968	51.4	23.6	$2,148,000
1969	54.2	24.9	$2,266,000
1970	57.0	26.2	$2,384,000
1971	60.2	27.7	$2,521,000
1972	63.4	29.2	$2,657,000
1973	66.6	30.6	$2,785,000
1974	69.8	32.1	$2,921,000
1975	73.0	33.6	$3,058,000
		TOTAL 1960-1975	$33,871,000

c. Cost of Cancellations

When adverse weather conditions force an airline to cancel a scheduled flight, the carrier loses revenue and is subjected to additional expense. Although some savings are realized in the elimination of direct operating costs of flying the cancelled trip, the net result is a loss to the airline.

Additional operating expenses are incurred as a result of:

- Interrupted trip expense - hotel rooms, meals, and ground transportation of passengers
- Duplicate ticketing expense - altering or rewriting tickets, obtaining alternate reservations, and handling ticket refund requests
- Non-revenue ferry mileage expense - non-revenue ferry flights required to re-position aircraft and restore flight schedules to normal

Interrupted Trip Expense - This item includes all expenses allowed or paid for the care and serving of passengers because of unscheduled interrupted passenger journeys. Such expense, reduced to unit cost per revenue passenger mile for the years 1959 and 1960, and the first six months of 1961, has been calculated and the portion due to weather conditions estimated. Using FAA forecasts of revenue passenger miles[1] as a basis, projections have been made through 1975 and are presented in Table 17. The data for this analysis were obtained from the airlines' reports on CAB Form 41; it should be noted that the amounts so reported specifically exclude the costs of forwarding passengers by surface common carrier or ticket refunds and, therefore, are probably underestimated. Interrupted trip expense is incurred in the case of diversions as well as cancellations, but no information is available as to the distribution of expense between the two causes. Accordingly, for the purpose of this analysis, it has been assumed that one-third of this expense is incurred in the case of cancellations and two-thirds in the case of diversions, the latter normally being more involved and consequently more expensive.

Duplicate Ticketing, Reservations, etc. - As in the case of diversions, cancellations involve additional expense to the airlines in altering or reissuing tickets, making new reservations, etc. This is estimated to amount to two percent of the total booked revenue on the flight.

Non-revenue Ferry Mileage Expense - Ferry mileage has been estimated to comprise approximately 10% of the total non-revenue mileage flown by domestic airlines, the remainder being primarily for training, proficiency checks, etc. Of the total ferry mileage, it has been assumed that one-half is flown for the purpose of re-positioning aircraft in order to restore normal schedules after disruption due to flight cancellations. Non-revenue mileage has

[1] "Aviation Forecasts, Fiscal Years 1962-67", Economics Branch, Air Commerce Division, Office of Plans, Federal Aviation Agency.

been estimated to comprise 1.6% of the total revenue mileage for domestic airlines[1]. Combining these two estimates results in a final figure of 0.08% of the total revenue aircraft miles which are flown to reposition aircraft after weather-caused flight cancellations. An annual projection of this expense has been made, based on FAA forecasts of revenue aircraft miles[2] through the year 1975, and is presented in Table 18.

Lost Passenger Revenue - In the case of a flight cancellation, a certain portion of the passengers, particularly on shorter flights, will turn to alternate means of transportation i.e., rented automobile, railroad, or bus, since it is possible for them to reach their intended destination within a few hours of the time originally planned. On the other hand, passengers on long-haul flights do not have this alternative and must wait for the weather to improve, taking a later flight. Thus, the portion of the original passengers on the cancelled flight who still utilize air transportation varies directly with the length of the particular trip involved. A previous study[3], using a sliding scale of passenger retention according to trip length and the CAB Origination - Destination Air Traffic Survey for 1958, arrived at a weighted average rate of passenger air traffic retention of 47%. Using an average revenue figure per flight, as estimated on page 64 , the average loss of revenue per cancelled flight (53%) has been estimated for the entire domestic airline industry. This figure has been applied to the forecast number of airline flights through 1975[4] in arriving at estimated losses of revenue due to weather-caused flight cancellations through 1975. No attempt has been made to forecast changes in fares or load factors in these calculations.

---

[1] "National Requirements for Aviation Facilities, 1956-1975"

[2] Cited 1, pg. 61

[3] "Forecasts of Losses Incurred by U. S. Commercial Air Carriers due to Inability to Deliver Passengers to Destination Airports in all-weather conditions, 1959-1963" United Research, Inc., March 1961

[4] "Forecasts of Air Traffic Activity, CONUS 1960-75, "Traffic Analysis Branch, Systems Engineering Division, ARDS, FAA, Sept. 1961

Summary

Using the assumptions set forth in the preceding sections, the estimated costs of flight cancellations through 1975 have been calculated and are presented in Table 18. The basic data used in these estimates, as well as those for diversions, are presented in Table 19.

Table 18. Estimated Costs of Flight Cancellations Due to Weather 1960-1975 (millions of dollars)

Gross	1960	1965	1970	1975
Revenue Loss[1]	$13.48	$17.41	$23.63	$30.95
Passenger Interrupted Trip Expense[2]	$ 0.42	$ 0.60	$ 0.80	$ 1.02
Duplicate Ticketing Reservations, etc.[3]	$ 0.51	$ 0.66	$ 0.75	$ 0.98
Non-revenue ferry mileage[4]	$ 1.16	$ 1.43	$ 1.61	$ 1.71
Gross Costs	$15.57	$20.10	$26.79	$34.66
Less Savings on Direct Operating Expense	$10.03	$13.76	$15.42	$16.66
Net Costs of Cancellations	$ 5.54	$ 6.34	$11.37	$18.00
Number of Flight Cancellations due to Weather[5]	45,400	54,400	63,700	73,700
Average Cost per Cancellation	$122	$116	$179	$244

[1]Estimated as 53% of total revenue booked on flights cancelled due to weather

[2]Estimated as one-third of total passenger interrupted trip expense due to weather

[3]Estimated as 2% of total revenue booked on flights cancelled due to weather

[4]Estimated as 5% of non-revenue aircraft mileage.

[5]Estimated as 1.19% of scheduled flights: "Forecasts of Air Traffic Activity, CONUS, 1960-1975, Traffic Analysis Branch, Systems Engineering Division, ARDS, FAA, September 1961, and page 52.

Table 19. Basic Data Used in Estimating Loss Due to Cancellations and Diversions due to Weather

	1960	1965	1970	1975
Average Revenue per Trip	$560	$604	$700	$792
Average Revenue Loss per Flight Cancellation	$297	$320	$371	$420
Total Operating Cost per Flight	$375	$390	$376	$347
*Direct Operating Cost per Flight	$243	$253	$242	$226
Average Airline Fleet Speed (mph)	236.2	313.8	363.0	390.7
Average Cost per Flight Mile	$1.53	$1.55	$1.51	$1.44
Average Duration per Airline Flight (hours)	1.01	0.78	0.66	0.60
Number of Airline Flights (millions)	3.81	4.57	5.34	6.19
Revenue Aircraft Miles (millions)	910.6	1119.6	1281.6	1448.5

*Estimated at 65% of total operating cost.

7. Diversions

a. Costs of Diversions

When an aircraft on a scheduled flight is unable to land at its destination airport and diverts to an alternate terminal, additional operating expenses are incurred by the airline due to:

- Additional flying time
- Non-revenue ferry flight
- Passenger interrupted trip expenses
- Duplicate ticketing and reservation service

Flight Expense - Diversion of an aircraft to an alternate airport usually involves additional flying time over and above that scheduled for the flight, which may involve, holding over the original destination, flying to the vicinity of the alternate airport, and holding over the alternate. To arrive at cost figures it is estimated that the average additional flying time for the domestic carriers in the event of a diversion is on the order of one hour. In estimating the annual number of diversions through 1975, it has been assumed that the 1960 ratio of diversions to cancellations (14.3%) will remain constant.

Ferry Flight - The diversion of an aircraft to an alternate airport produces a disruption in the planned positioning of aircraft to carry out future flight schedules. Restoration of scheduled operations at the original destination airport depends upon the availability of suitable aircraft. This can be accomplished through substitution or by ferrying. The ferrying may not necessarily involve the particular diverted aircraft but one at a closer or more convenient location. Accordingly, it is estimated that each diversion, on the average, will involve one-half hour of non-revenue ferry flight as an additional expense.

Passenger Interrupted Trip Expense - The expenses incurred in providing accomodations, ground transportation, etc., to passengers on diverted trips are considerably greater than those involved in cancellations.

In the case of cancellations, the point of origin of the flight is likely to be the residence of a considerable number of the booked passengers. However, with a diversion, the point of arrival is neither the home city nor the planned destination of the passengers. Since the interrupted trip expenses reported by the airlines are not separated by cause, it is estimated that two-thirds of the total are due to diversions and one-third to cancellations. (Table 20).

Duplicate Ticketing Expense - The additional expenses incurred in altering or reissuing tickets, making alternate reservations, and handling ticket refunds are primarily a function of the number of passengers involved which in turn is closely related to the amount of revenue received for the cancelled flight. Previous studies[1] have arrived at a figure of two percent of the total revenue for the flight. Since no additional estimates have been produced since that time, we shall use that figure. Annual cost estimates under this item are presented in Table 20.

Table 20. Estimated Costs of Flight Diversions due to Weather 1960-75 (per flight)

	1960	1965	1970	1975
In-flight delay (1 hr)	$375	$500	$570	$578
Ferry flight (one-half hour)	$188	$250	$285	$289
Interrupted trip expense	129	154	175	193
Duplicate ticketing, etc.	11	12	14	16
Total Expense per Diversion	$703	$916	$1044	$1076
Number of diversions due to weather[2]	6500	7800	9100	10,500
Total cost of diversions(millions)	$4.57	$7.15	$9.50	$11.30

[1] Passenger Credit Plan Investigation, CAB Docket 10917

[2] The assumption has been made that the ratio of diversions to cancellations in 1960 (14.3%) will remain essentially constant through 1975.

A special case of large penalties due to diversions exists at Los Angeles International Airport. Due to peculiar climatic conditions at this terminal, below landing minimums frequently exist in a highly localized area, while nearby terminals such as Ontario, California, located about 30 miles east, are clear. Therefore, most turbojet aircraft, which are unable to land at Los Angeles, presently divert to Ontario.

A detailed analysis of the cost of 1961 Ontario diversions is given in Appendix F.

8. Off-Loading Due to Elevated Runway Temperatures

Surface temperatures at time of take-off have a direct effect on take-off gross weight of the aircraft for a given runway length. On hot days air densities are lower than on cold days and for a constant amount of thrust longer take-off runs are required. If the take-off weight exceeds the limits set for a particular runway, the aircraft take-off gross weight must be reduced.[1]

Off-loading may be accomplished by reducing the airplane's fuel load and by planning for cruising altitudes at which the engines operate with lower fuel consumption. In addition to fuel, cargo and passengers may be taken off the aircraft. The graph presented in Figure 11 shows that the allowable gross weight, or in the case of a particular type aircraft and trip length the allowable payload, decreases with increasing runway temperatures. In our example, which depicts the DC-8 turbojet, with JT3C-6 engines, loaded for a transcontinental flight, the allowable payload decreases approximately 1800 lbs. per 10°F up to a runway temperature of 70°F. Above this temperature the drop in allowable payload is more than 4000 lbs. per 10°F up to a runway temperature of 110°F. At this temperature the total payload of the transcontinental DC-8 is reduced to 4000 lbs.from a value of 20,000 lbs. at 70°F.

In actual operations, the cost penalties involved in off-loading are not significant, since only a relatively small percentage of all jet flights are carried out with maximum allowable payloads. Moreover, since accurate temperature forecasts are usually available at turbojet airports, the cases where a fully loaded aircraft on take-off encounters runway temperatures appreciably higher than those forecast are relatively infrequent. The question of rapidly changing runway temperatures is basically a summertime problem and only at those airports where an interplay of land and sea breezes is involved.

[1]Thus, since during flight planning the limiting gross weight of the aircraft is determined from a forecast of runway temperatures, this weight must be modified if the observed temperatures at take-off time are markedly higher than those forecast.

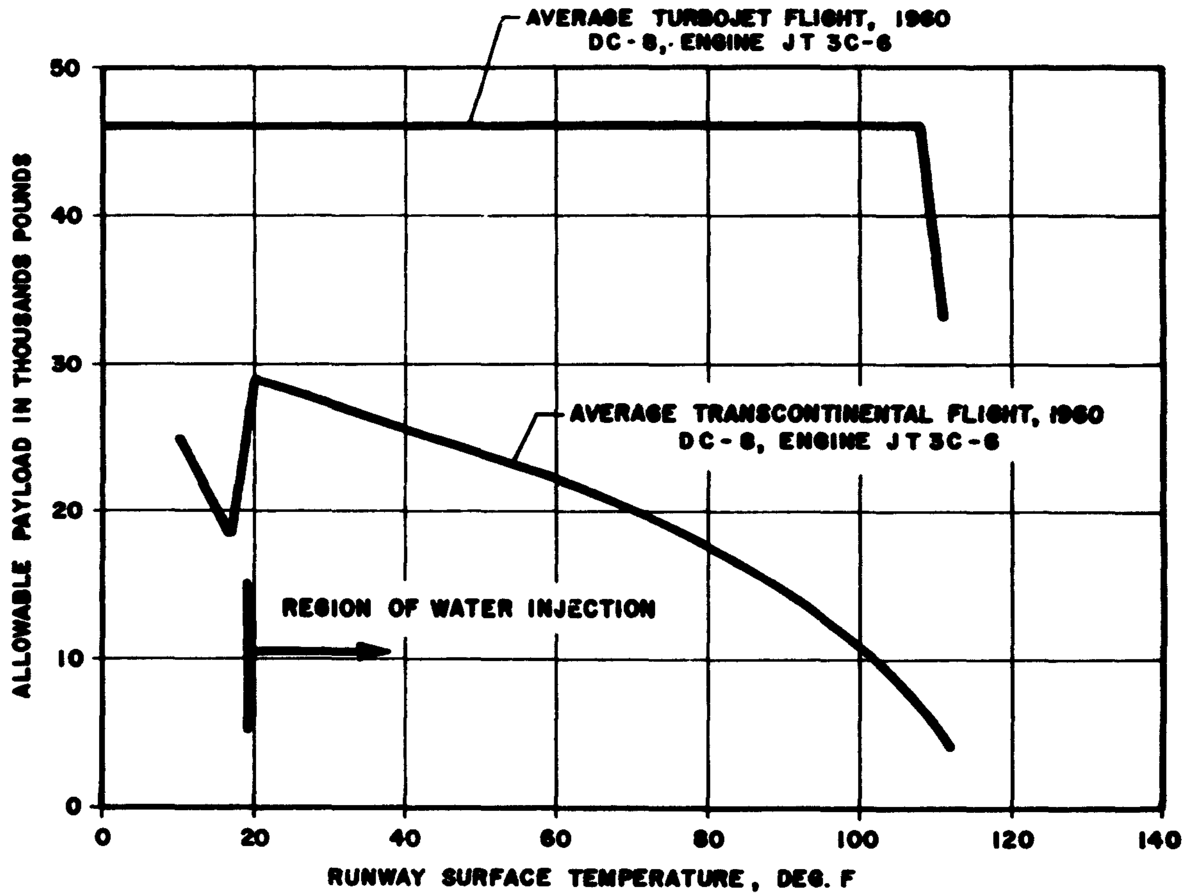

FIGURE 11. EFFECT OF RUNWAY SURFACE TEMPERATURE ON ALLOWABLE PAYLOAD DC-8 TURBOJET

For the above reasons, no attempt has been made to estimate the costs incurred by the airlines due to off-loading, even though some 20,000 transcontinental jet flights are made annually by the major trunk lines.

Enroute temperature differences are shown in Table 2 to be of relatively minor importance to turbojet operations and of no importance to piston operation costs. However surface temperatures at time of take-off are important to certain turbojet flights in pre-planning the gross weights and payload for the flight. Accurate forecasting of temperatures can influence fuel load, fuel stops, off-loading of payload, and other factors which are economically important.

Tables 21, A and B, illustrate a typical effect of surface temperatures on an average jet flight (1960) DC-8 powered with JT3C-6 engines as well as the effect on an average transcontinental flight.

Figure 11, shows graphically the same effect. From this graph, it can be seen that the average short or medium distance turbojet flight in 1960 would not have been influenced by temperatures whereas each transcontinental flight can be influenced to a considerable degree. At 70°F for example, a ten degree forecast error in surface temperature at time of departure could result in an 1800 pound difference in allowable payload for the transcontinental flight but would have no effect on the allowable pay of the short or medium distance flight.

In addition to the summer temperature effect on the longer flights, terminal surface temperatures at the higher altitudes have an appreciable effect on gross take-off performance. This problem also occurs at airports with runway length restrictions. On many occasions during high temperatures, the actual usable load cannot be determined until just before dispatch. Reducing the gross in these cases to conform with the aircraft's performance is done by either reducing the fuel load with or without a planned fuel stop, off-loading cargo, mail, or passengers in order of their importance.

Table 21. Effect of Runway Temperature on Allowable Payload

Aircraft Type: DC-8 Turbojet

Engines: JT3C-6

A. AVERAGE DOMESTIC FLIGHT LENGTH: 3.7 hours

Total Fuel Carried:

Fuel consumed	48,000 lbs.
FAA Req. and Reserve Fuel	12,000 lbs.
Min. alternate fuel	6,000 lbs.
Total Fuel	66,000 lbs.

An average flight of 3.7 hours would require the gross weight at take-off to be restricted by the landing weight and not by the runway temperature.

Max. landing weight	193,000 lbs.
Fuel consumed	48,000 lbs.
Max. Take-off Weight	241,000 lbs.

In order to determine the allowable payload, the weight empty of 128,800 pounds and the total fuel of 66,000 pounds is subtracted from the maximum take-off weight:

Max. take-off weight	241,000 lbs.
Less weight empty	128,800 lbs.
Less total fuel	66,000 lbs.
Allowable Payload	46,200 lbs.

This allowable payload is virtually constant with runway temperatures up to 100°F. See Figure 11.

Table 21. Effect of Runway Temperature on Allowable Payload (Cont'd.)

B. AVERAGE TRANSCONTINENTAL FLIGHT, 5:10 hours

Total Fuel Carried:

Fuel consumed	77,000 lbs.
FAA and Reserve fuel	12,000 lbs.
Min. alternate fuel	6,000 lbs.
Total fuel	95,000 lbs.

Runway Temperature in Deg. Fahrenheit		Max. Allowable Take-off Gross Weight	Transcontinental Allowable Payload
10	(no water	249,100 lbs.	25,300 lbs.
12	injection)	247,700 lbs.	23,900 lbs.
14		246,300 lbs.	22,500 lbs.
16		244,800 lbs.	21,000 lbs.
18		245,400 lbs.	19,600 lbs.
20	(water	253,400 lbs.	29,600 lbs.
30	injection)	251,600 lbs.	27,800 lbs.
40		249,700 lbs.	25,900 lbs.
50		247,900 lbs.	24,100 lbs.
60		246,100 lbs.	22,300 lbs.
70		244,200 lbs.	20,400 lbs.
80		242,400 lbs.	18,600 lbs.
90		238,500 lbs.	14,700 lbs.
100		233,300 lbs.	9,500 lbs.
110		228,200 lbs.	4,400 lbs.

9. **Summary of Total Penalties**

Table 22. Air Carrier Dollar Penalties (millions)

Item	1960	1965	1970	1975
In-Flight Delays	$8.69	$9.23	$9.76	$10.23
Passenger Delays	19.90	24.69	32.64	48.34
Maintenance Delays	8.74	11.26	13.05	14.20
Alternate and Contingency Fuel	7.02	38.80	71.46	106.09
Diversions	4.57	7.15	9.50	11.30
Cancellations	5.54	6.34	11.37	18.00
TOTALS	$54.46	$97.74	$147.78	$208.16

Table 22. presents the projected total penalties to the air carriers due to all weather causes.

PART I

PENALTIES DUE TO WEATHER

B. GENERAL AVIATION

1. Introduction
2. General Considerations
3. Accidents
   a. Present and Future Trend
   b. Weather Accidents
4. Casualties
   a. Fatalities
   b. Serious Injuries
   c. Minor Injuries
   d. Summary
5. Cost of Casualties
   a. Economic Loss from an Aviation Fatality
   b. Costs of Serious Injuries
   c. Costs of Minor Injuries
   d. Total Costs of Casualties
6. Aircraft Damage
   a. Average General Aviation Aircraft
   b. Aircraft Destroyed and/or Seriously Damaged
   c. Value of Average Aircraft
7. Total Cost of Aircraft Damaged and/or Destroyed
8. Delays Due to Weather
   a. Estimated Hours of Delay
   b. Direct Operating Costs
   c. Loss of Passenger Time
   d. Loss of Utilization
9. Diversions and Cancellations
   a. Occurrence of Diversion and Cancellations
   b. Cost of Diversion due to Weather
   c. Cost of Cancellations
10. Summary of Total Penalties

PART I

B. GENERAL AVIATION

B. GENERAL AVIATION

1. Introduction

This section presents an estimate of the costs of general aviation casualties, equipment damage, and delays due to weather causes. These costs have been computed from presently available data up to the year 1960. In addition, projections of casualties and aircraft damage in the 15 year period ahead, 1960-1975, have been made.

The subject matter has been grouped by estimates of casualties, such as fatalities, serious injuries and minor injuries, by estimates of aircraft destroyed, seriously damaged and suffering minor damage, and by estimates of costs involved in the case of delays. Based on data compiled from aviation insurance underwriters and aircraft manufacturers, average figures for aircraft damage and the values of current general aviation aircraft have been computed. An analysis of the economic loss from an aviation fatality has been presented, permitting the establishment of a dollar value of lives lost in general aviation due to weather in the 15 year period ahead.

2. General Considerations

The largest segment of the airspace users is the general aviation group. In 1960 this group comprised some 72,000 aircraft and by 1970 it will have grown to over 100,000 according to latest FAA forecasts[1]. By 1970 this large fleet will fly over 18 million hours in contrast to the air carriers which will log an estimated total of only 4 million hours and the military which will fly an estimated 7 million hours[2]. General aviation has the largest incidence of casualties and aircraft damage due to weather causes. It is logical to conclude that this group will continue to have a relatively large incidence of accidents and other disruptions such as delays, cancellations and diversions. This analysis concerns itself with the present penalties on general aviation due to weather causes. It also projects the trend of these penalties into the 15 year period ahead.

In examining such penalties as delays, cancellations and diversions, which general aviation must pay due to various weather causes, one is confronted with the fact that these penalties are considerably more difficult to estimate than for air carriers. No statistics exist for the number of hours of passenger delays which general aviation experiences each year due to weather. No records are kept of cancelled flights since general aviation pilots as a rule do not fly on a schedule. Diversions, where due to weather the aircraft lands at a terminal other than the original destination, are likewise not reported. In looking at the costs to the passengers involved in these penalties, however, they are just as real as those for air carrier passengers. A large part of general aviation flying is for pleasure with delays and cancellations of little economic consequence. However, business flying comprises the greater share of general aviation activities.

---

[1] "Forecasts of Air Traffic Activity in the Continental U.S. 1960-1975", Traffic Analysis Branch, Aviation Research and Development Service, FAA

[2] Cited 1.

A representative breakdown of the proportion of pleasure flying out of the total general aviation flying is given by the compilation of hours flown in general aviation by type of flying in Table 23 for the years 1931 to 1960[1]. The figures indicate that the aggregate of business, commercial, and instructional flying in 1960 amounted to 76% of all general aviation flying hours. Thus, the financial loss in general aviation flying caused by delays and cancellations cannot be overlooked, although an exact determination of this loss is difficult due to the lack of statistics.

---

[1] "FAA, Statistical Handbook of Aviation", 1961 Edition

Table 23. Hours Flown in General Aviation, by Type of Flying 1931-1960 (Thousands of Hours)

Year	Total Hours	Business		Commercial		Instructional		Personal	
		Hours	Per-cent	Hours	Per-cent	Hours	Per-cent	Hours	Per-cent
1931	1,083	152	14	281	26	307	28	343	32
1932	877	130	15	215	25	223	25	309	35
1933	795	129	16	200	25	198	25	268	34
1934	846	121	14	207	24	217	26	301	36
1935	954	132	14	229	24	292	31	301	31
1936	1,059	122	12	245	23	380	36	312	29
1937	1,173	156	13	227	19	432	37	358	31
1938	1,478	188	13	254	17	577	39	459	31
1939	1,922	246	13	332	17	755	39	589	31
1940	3,200	314	10	387	12	1,529	48	970	30
1941	4,460	250	6	511	11	2,816	63	883	20
1942	3,786	270	7	473	12	2,680	71	363	10
1946	9,788	1,068	11	943	10	5,996	61	1,686	17
1947	16,334	1,966	12	1,279	8	10,353	63	2,616	16
1948	15,130	2,576	17	1,066	7	8,701	58	2,606	17
1949	11,031	2,615	24	1,449	13	4,187	38	2,732	25
1950[1]	9,650	2,750	28	1,500	16	3,000	31	2,300	24
1951	8,451	2,950	35	1,584	19	1,902	23	1,880	22
1952	8,186	3,124	38	1,727	21	1,503	18	1,629	20
1953	8,527	3,626	42	1,649	19	1,248	15	1,846	22
1954	8,963	3,875	43	1,829	20	1,292	15	1,920	22
1956[1]	10,200	4,600	45	2,000	20	1,500	15	2,100	20
1957	10,938	4,864	45	2,013	18	1,864	17	2,109	19
1958[1]	11,700	5,300	45	2,200	19	2,000	17	2,200	19
1959[2]	12,000	5,300	44	2,200	18	1,900	16	2,600	22
1960	12,203	5,300	44	2,200	18	1,700	14	2,950	24

[1]Estimated. No survey was conducted covering the designated year.

[2]Revised estimate.

Source: 1931-42, CAA Nonscheduled Flying Reports, 1943-45, war years, no data available, 1946-59, CAA Survey of Aircraft Use, except as noted. 1960, Aircraft Use and Inspection Report (Form ACA-2350).

3. Accidents

It is difficult to distill from the records[1] of general aviation accidents over a period of 21 years (1938-1959) a clear cut trend which can be extrapolated for the purpose of predicting the incidence of general aviation accidents in the 15 year period ahead. The curve plotted in Figure 12 reveals that, in the period prior to 1945, accident occurrence was quite erratic with a high of over 4,000 accidents reached in 1941. In the 5 years following World War II, accidents increased almost 3 fold, owing to the fact that a large number of returned service men took up flying in small, general aviation aircraft, thereby creating the post war flying boom with the corresponding high accident rate. Subsequently, a somewhat more even trend is noticeable with the apparent start of a new increase in accidents occurring in the years 1957-1959.

a. Present and Future Trend

It is evident from the above that a different approach must be used to project an expected general aviation accident trend into the period covering the years 1960 to 1975. A logical basis for such an approach is to examine the total number of hours flown during 1938-1959, since the probability of accident occurrence is directly related to the length of time the pilot and the aircraft are exposed to the flight environment. A plot of the total number of hours flown in general aviation, Figure 13, reveals a recognizable trend which is compatible with official FAA predictions of hours flown in the 15 year period ahead, Table 24. When the past rate of accident occurrence per million hours flown is plotted, the curve shows a smooth trend of continuously decreasing amplitude which levels off in 1960 to an almost constant rate of 300 accidents per million hours flown, Figure 14. The reason for this leveling off is thought to be the technical improvements made in light planes and light plane engines, which have greatly reduced the number of

[1] The recorded data on general aviation accidents were compiled and tabulated by the Civil Aeronautics Board before 1954. Effectived January 1, 1954, the Civil Aeronautics Administration (now the Federal Aviation Agency) took over the task of investigating accidents involving fixed-wing aircraft of 12,500 pounds gross weight or under. In addition, statistics of serious injuries are available from the year 1954 on, as well as a compilation of aircraft destroyed and/or severely damaged.

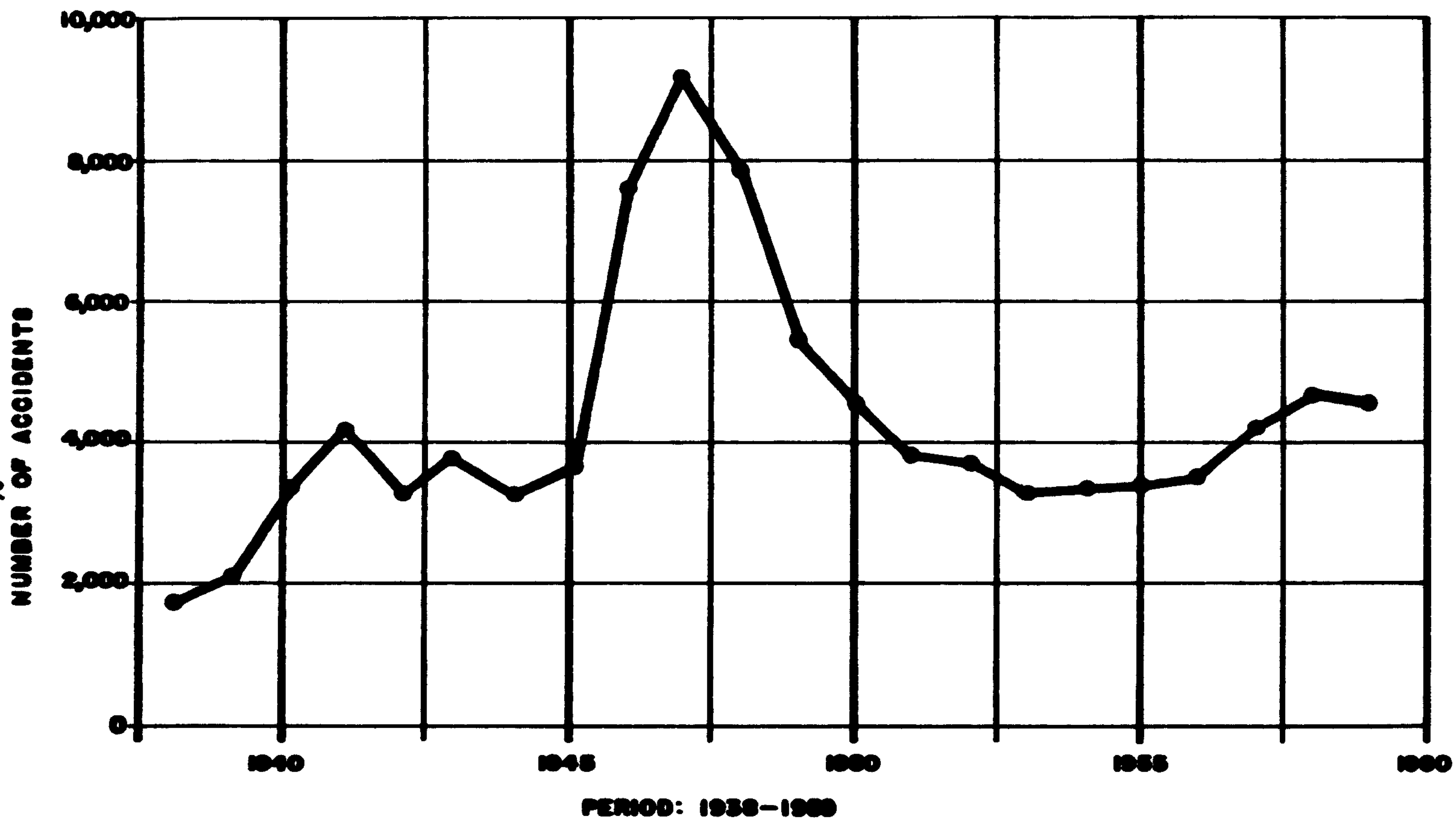

FIGURE 12. GENERAL AVIATION, TOTAL NUMBER OF ACCIDENTS

REF: "STATISTICAL REVIEW, GENERAL AVIATION ACCIDENTS," CALENDAR YEAR 1959, CAB

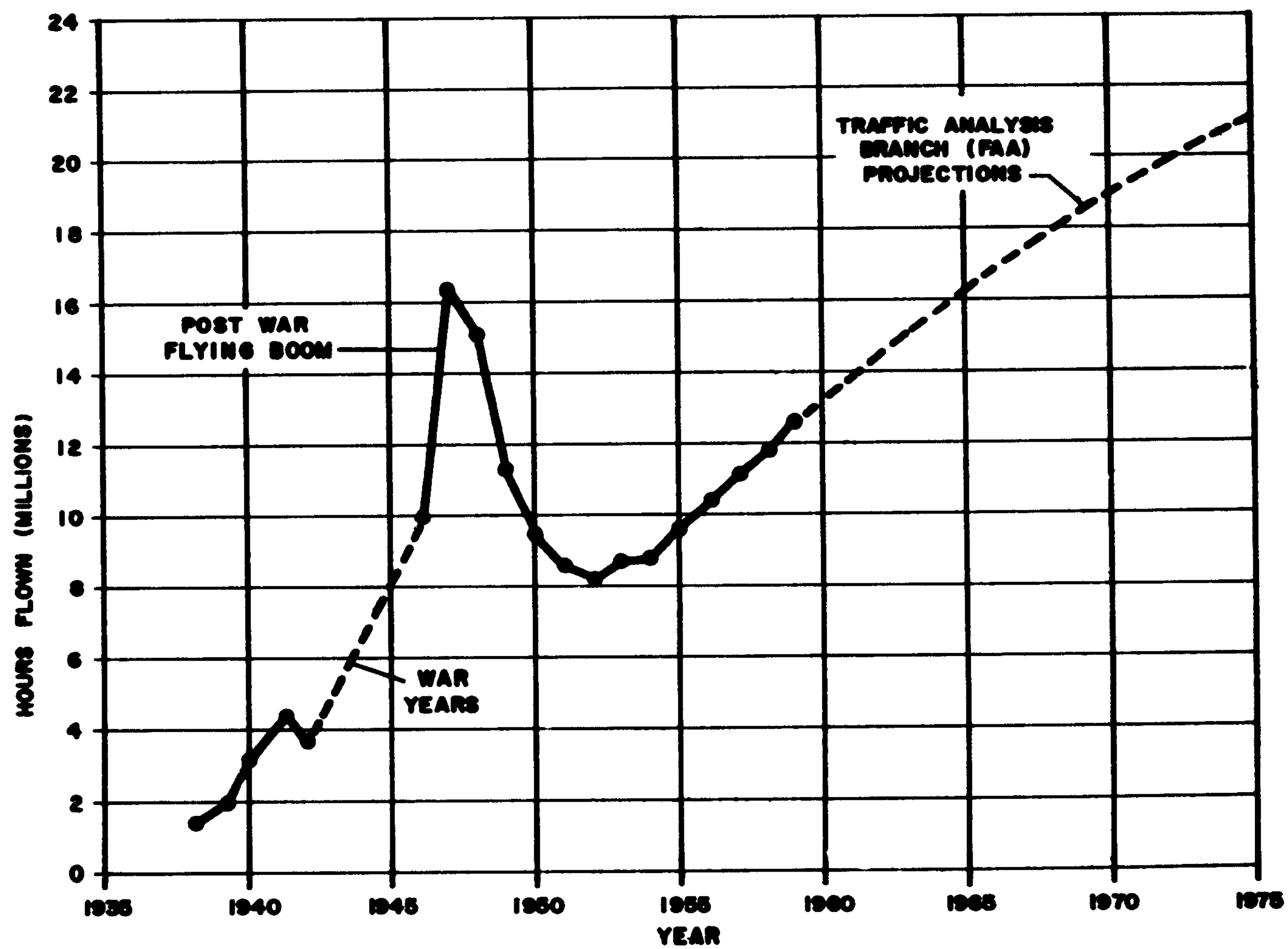

FIGURE 13. GENERAL AVIATION TOTAL HOURS FLOWN

REF: "STATISTICAL REVIEW, GENERAL AVIATION ACCIDENTS." CALENDAR YEAR 1959, CAB

Table 24. Forecast of Aircraft Flying Hours Continental U.S. 1960-1975 (millions)[1]

Ownership and Aircraft Class	Year			
	1960	1965	1970	1975
Total	26.65	28.17	29.47	31.44
Piston	20.53	20.15	20.68	22.13
Turboprop	.71	1.57	1.52	1.33
Turbojet	4.61	5.11	5.15	5.56
Helicopter	.80	1.34	2.12	2.42
Air Carrier	4.03	3.79	3.90	4.23
Piston	3.02	1.58	.86	.60
Turboprop	.59	.92	.93	.80
Turbojet	.39	1.23	1.99	2.67
Helicopter	.03	.06	.12	.16
General Aviation	12.20	15.70	18.50	21.00
Piston	11.98	14.94	17.24	19.48
Turboprop	.02	.15	.20	.25
Turbojet	a/	.02	.05	.07
Helicopter	.20	.59	1.01	1.20
Military	10.42	8.68	7.07	6.21
Piston	5.53	3.63	2.58	2.05
Turboprop	.10	.50	.39	.28
Turbojet	4.22	3.86	3.11	2.82
Helicopter	.57	.69	.99	1.06

a/ Less than 5,000 hours

[1] Traffic Analysis Study, Forecasts of Air Traffic Activity, Continental U.S. 1960-1975 Traffic Analysis Branch, Federal Aviation Agency, September 1961.

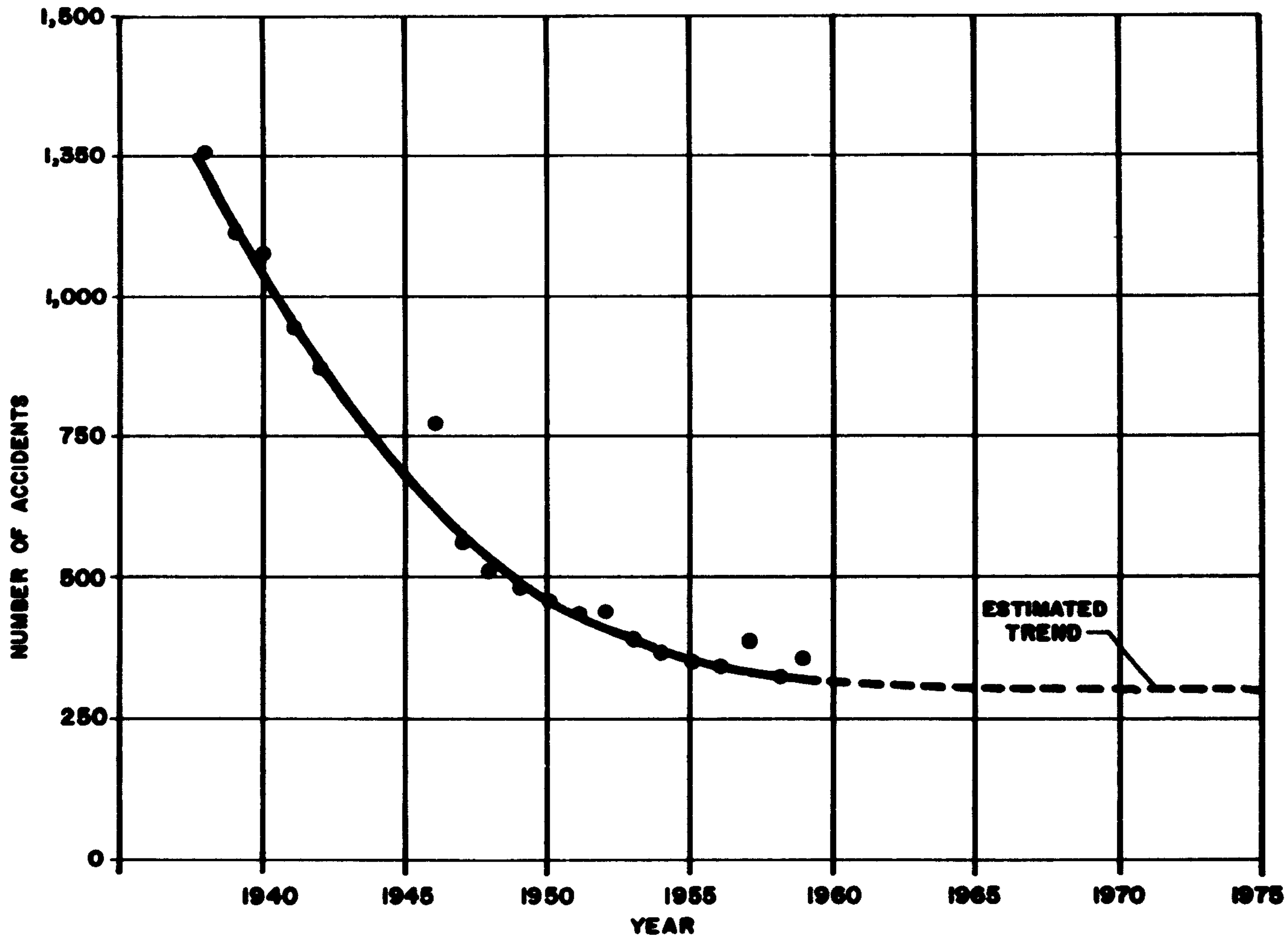

FIGURE 14. GENERAL AVIATION, TOTAL ACCIDENTS PER MILLION HOURS FLOWN

REF.: "STATISTICAL REVIEW, GENERAL AVIATION ACCIDENTS," CALENDAR YEAR 1959, CAB

accidents due to mechanical failure. This constant accident rate has been projected to the period 1975. Estimates of total number of general aviation accidents can thus be made by multiplying the total hours flown by the projected accident rate. In this manner estimates of general aviation accidents can be made for the next 15 years:

Year	1960	1965	1970	1975
Accidents	4700	5300	5800	6300

b. Weather Accidents

When making an attempt to single out general aviation accidents due to weather, an important factor is that there is frequently more than one cause for an aviation accident. Another factor is that not every accident is reported to the authorities. Thirdly, many situations result in near accidents in the air or on the ground, which never reach the accident files. These are mostly the result of weather causes. This report does not attempt to estimate the number of near accidents occurring every year in general aviation. Likewise no estimates of non-reported accidents are included. The material presented here is based exclusively on available official statistics compiled by the Civil Aeronautics Authority, the Federal Aviation Agency and the Civil Aeronautics Board.[1]

It is comparatively rare that an accident is due solely to one well defined cause. Usually a combination of causes, which may include pilot judgment, navigational errors, misinterpretation of weather forecasts and improper flight planning before take-off, are responsible for the accidents. Even those accidents labeled as pure weather accidents may have more than one cause. As an example, we quote here from the 1956 Statistical Analysis of General Aviation Accidents[2], "In tabulating cause factors, no one cause

[1] General Aviation Accidents (Non-Air Carrier), A Statistical Analysis, Calendar Year 1956.

[2] Cited 1 above.

was selected as a primary cause since frequently two or more cause factors were involved. All probable cause factors contributing to an accident were counted. Thus, there are more cause factors than accidents. The most common cause factors in accidents for 1956 were:

1.	Lost directional control on ground	458
2.	Inadequate flight planning	448
3.	Failed to maintain airspeed	435
4.	Operated in unsuitable area	346
5.	Landed too fast or too far down runway	196
6.	Weather	1003"

The above listing shows that weather could have played a part in several of the other quoted causes, such as gusts or cross winds in case 1, lack of weather briefing in cause 2, or poor visibility in cause 3.

If all accidents in which weather was at least one of the contributing factors were considered, our projections would probably have to be increased by 20% to 30%[1]. A typical breakdown for the year 1956 of the weather accidents listed above shows the following:

Low Ceiling	128
Fog	91
Clouds	9
Rain	54
Thunderstorms	21
Downdraft	
Turbulence	
Wind (includes cross-wind and gusts)	518
Snow, sleet, or hail	28
Miscellaneous unsafe conditions	88
Undetermined	10
Total	1003

[1] From discussions with CAB and FAA personnel.

This breakdown shows that by far the most frequent cause of weather accidents is wind, including gusts and cross-winds on runways. Wind accounts for approximately half of all weather accidents.

An analysis of available statistics shows that a constant factor of approximately 30% of all accidents may be attributed primarily to weather causes which range from low ceiling and fog to gusts and cross-winds on the runway. Accidents in which weather was a contributing cause make up more than 50% of all general aviation accidents. Applying this 30% factor to the total number of general aviation accidents expected within the next 15 years, the predicted number of accidents due to weather becomes (Figure 15).

Year	1960	1965	1970	1975
Accidents	1400	1600	1760	1900

4. **Casualties**

The losses suffered in general aviation accidents extend from casualties, such as fatalities or serious and minor injuries, to equipment damage, where aircraft are destroyed or severely damaged.

a. Fatalities

In projecting general aviation fatalities due to weather into the future and estimating an economic cost figure for them based on the loss of productivity to the national economy, available statistics had to be examined for a trend or factor as a basis for these projections.

In comparing the number of fatal accidents due to weather to all general aviation accidents, a constant ratio of slightly over 6% was found for the years 1954-1957. It is of interest to note that fatal accidents due to all causes amounted to an average of 10% of all general aviation accidents for the same period. Thus, over half of all fatal accidents in general aviation during this period were directly attributable to weather causes. If fatal accidents in which weather was one of several contributing causes were included, the percentage would undoubtedly be much higher. These figures clearly point out the fact that weather, and in many cases the failure on the part of the pilot to properly assess the effects of weather, is a principal killer of general aviation.

Estimates of fatal accidents are tabulated below and are presented in Figure 15.

Year	1960	1965	1970	1975
Fatal Accidents	290	330	360	390

To arrive at a reasonable estimate of the number of fatalities during the 15 year period ahead, the rate of fatalities per fatal accident was examined. A definite trend was found in the number of persons killed per fatal accident. Statistics collected by the CAB[1] since 1938 (Table 25) show

[1] Statistical Review, General Aviation Accidents, Calendar Year 1959, Civil Aeronautics Board

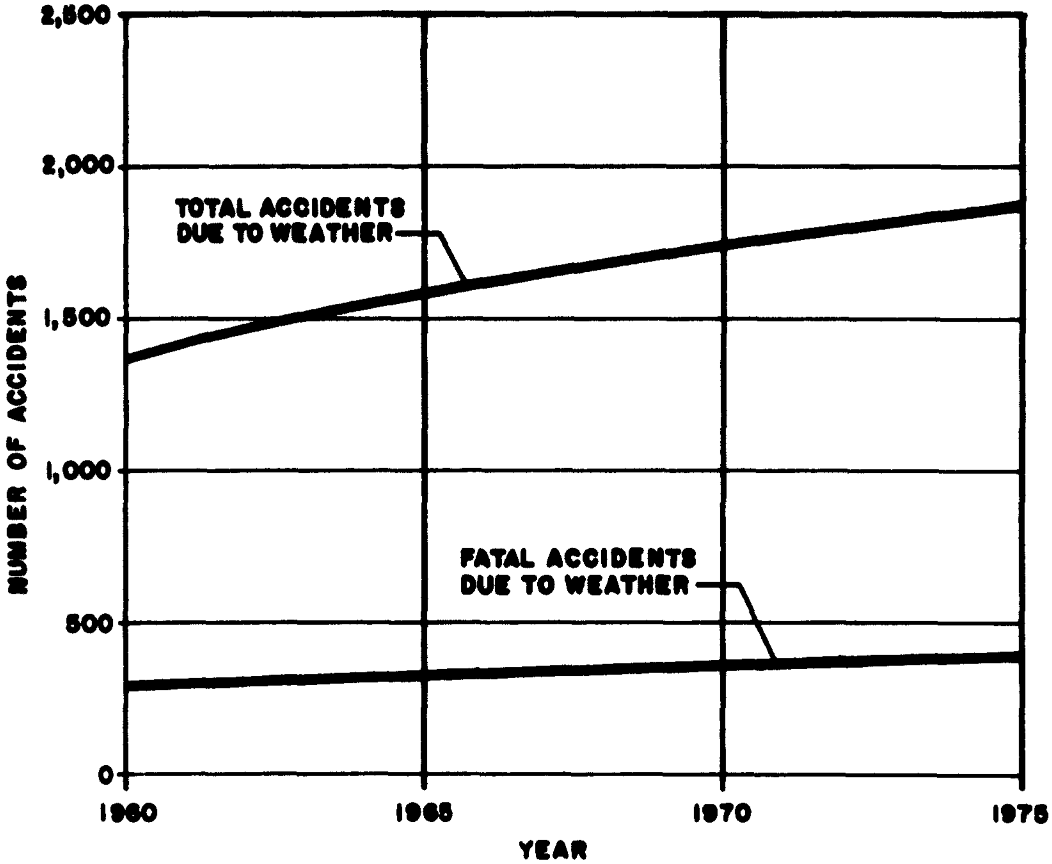

FIGURE 15. PREDICTED GENERAL AVIATION ACCIDENTS DUE TO WEATHER 1960-1975

Table 25. Accidents, Fatalities, Accident Rates General Aviation
1938- 1959

Year	Accidents: Total	Accidents: Fatal	Fatalities	Hours Flown (000)	Plane-Miles Flown (000)	Accident Rates: 100,000 Hours		Accident Rates: Million Plane-Mi.	
						Total	Fatal	Total	Fatal
1938	1,861	176	274	1,478	129,359	125.7	11.8	14.4	1.4
1939	2,222	203	315	1,922	177,868	117.0	10.7	12.5	1.1
1940	3,471	232	359	3,200	264,000	108.5	7.3	12.1	0.9
1941	4,252	217	312	4,460	346,303	94.5	4.8	12.3	0.6
1942	3,324	143	220	3,786	293,593	87.5	3.8	11.3	0.5
1943	3,871	167	257	NA	NA	NA	NA	NA	NA
1944	3,343	169	257	NA	NA	NA	NA	NA	NA
1945	4,652	322	508	NA	NA	NA	NA	NA	NA
1946	7,618	690	1,009	9,788	874,740	77.7	7.0	8.7	0.8
1947	9,253	882	1,352	16,334	1,502,420	56.7	5.4	6.2	0.6
1948	7,850	850	1,384	15,130	1,469,540	52.0	5.6	5.3	0.6
1949	5,459	562	896	11,031	1,128,992	49.6	5.1	4.8	0.5
1950	4,505	499	871	9,650	1,061,500	46.4	5.2	4.2	0.5
1951	3,824	441	750	8,451	975,480	45.0	5.2	4.0	0.5
1952	3,657	401	691	8,186	972,055	44.6	5.0	3.8	0.4
1953	3,232	387	635	8,527	1,045,346	38.0	4.6	3.1	0.4
1954	3,380	393	684	8,963	1,119,295	37.6	4.4	3.0	0.4
1955	3,343	384	619	9,500	1,216,000	35.2	4.0	2.7	0.3
1956	3,474	356	669	10,200	1,315,000	34.0	3.5	2.6	0.3
1957	4,202	428	801	10,938	1,426,285	38.4	3.9	2.9	0.3
1958	4,135	398	731	11,700	1,544,000	39.2	3.4	3.0	0.3
1959	4,576	450	823	12,400	1,649,000	36.9	3.6	2.8	0.3

Ref: "Statistical Review General Aviation Accidents, Calendar Year 1959", Civil Aeronautics Board

that until 1945 this ratio remained fairly constant, at about 1.6 fatalities per fatal accident, Figure 16. Subsequently the ratio increased steadily until by 1960 it had reached a value of 1.9. Extrapolation of the curve, which exhibits a nearly straight line trend, leads to projected ratios of 2.0 for 1965, 2.1 for 1970 and in excess of 2.2 fatalities per fatal accident for 1975.[1]

The increase in the fatality rate per fatal accident is largely explained by the shift in composition of the general aviation fleet. Figure 19 shows the increasing percentage of single engine 4 seater aircraft in the private plane group and reveals a sharp decline in the number of aircraft with 1-3 places. An additional explanation of the increase in fatalities per accident is the greater impact speeds during accidents caused by the steadily increasing speed of private planes.

However, this increase in fatality rate is small and has been neglected. The 1960 value of 1.9 fatalities per fatal accident will be assumed to hold for the period to 1975.

The total number of estimated fatalities can now be obtained for the 1960-1975 period by multiplying the fatality ratios by the number of expected fatal accidents. Figure 17 shows the results which put the estimated number of fatalities due to all weather causes at:

Year	1960	1965	1970	1975
Fatalities	550	630	690	740

b. Serious Injuries

The projection of the number of serious injuries might be based on the total number of flying hours, or on the total number of accidents occurring during any given year. In order to single out the serious injuries

[1] Statistical Review, General Aviation Accidents, Calendar Year 1959, Civil Aeronautics Board

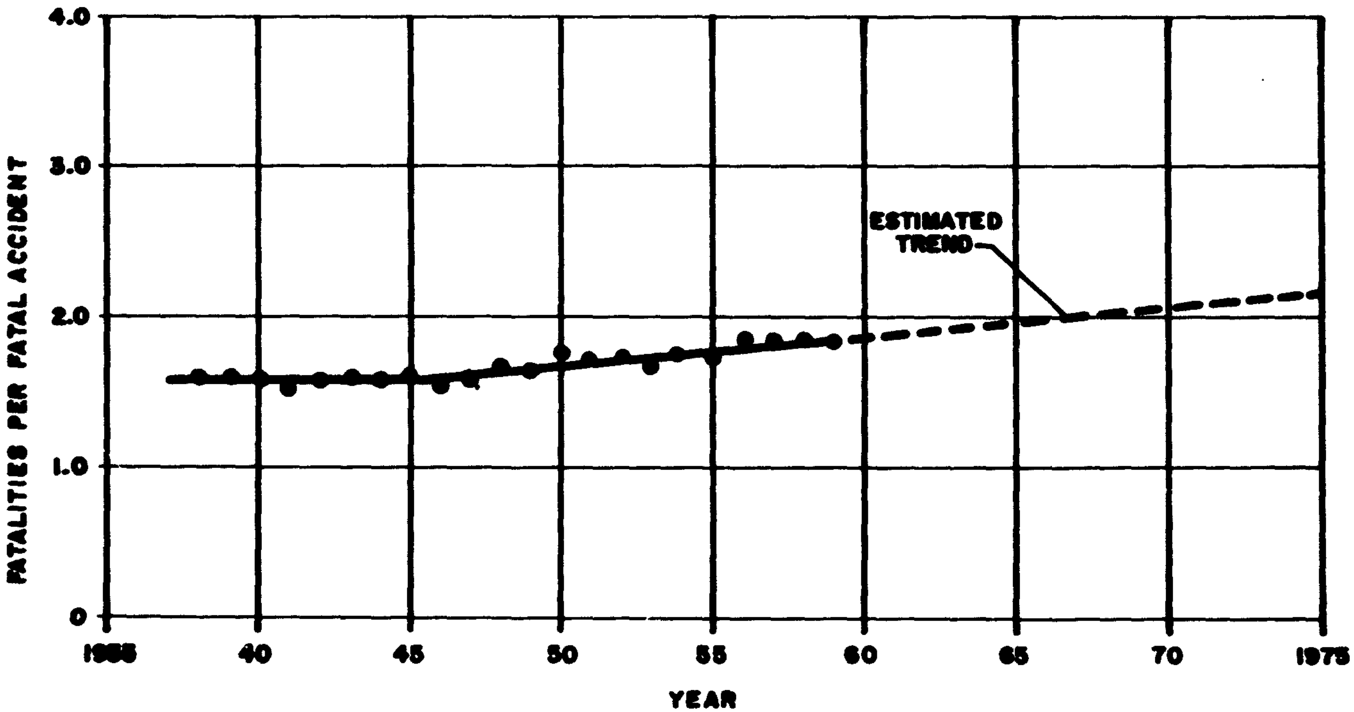

FIGURE 16. GENERAL AVIATION, NUMBER OF FATALITIES PER FATAL ACCIDENT (YEARS 1938-59)

REF.: "STATISTICAL REVIEW, GENERAL AVIATION ACCIDENTS," CALENDAR YEAR 1959, CAB

occurring in weather accidents, use has been made of the fact that they are usually connected with fatal accidents. Since the fatality rate is generally higher in weather accidents than in accidents due to all other causes, a ratio based on fatalities suffered in weather accidents represents the actual conditions with fairly good accuracy.

When the number of reported serious injuries is divided by the number of fatalities, a surprising consistency is found, in that an almost constant ratio of 0.54 exists for the years 1954, 1955, 1956 and 1959. In 1957 this ratio was somewhat lower (.45) and for 1958 no statistics have been published. Thus, in four out of five years reported, the ratio was almost constant. This is considered an adequate basis for our projections. These values for the 15 year period ahead, are:

Year	1960	1965	1970	1975
Serious Injuries	300	340	370	400

The curve in Figure 17 shows this trend graphically.

c. Minor Injuries

CAB statistics list only two categories of injuries; serious injuries and fatal injuries. Minor injuries have not been recorded. According to the records of aviation insurance underwriters, by far the largest portion of all injuries are minor injuries. Estimates place these at over 75% of all injuries sustained. Frequently passengers or pilots walk away from an accident with seemingly no injury, only to find out later that, for instance, slight spinal damage was sustained during the landing shock which was not felt during or shortly after the accident. Thus, minor injuries sustained from accidents are seldom reported, although they constitute a measurable portion of the economic costs of general aviation accidents. In the absence of recorded statistics we will estimate minor injuries as 3 times the number of serious injuries, based on the 75% figure indicated by the insurance companies. Thus the predicted number of minor injuries due to weather accidents for the 15 year period ahead is as follows:

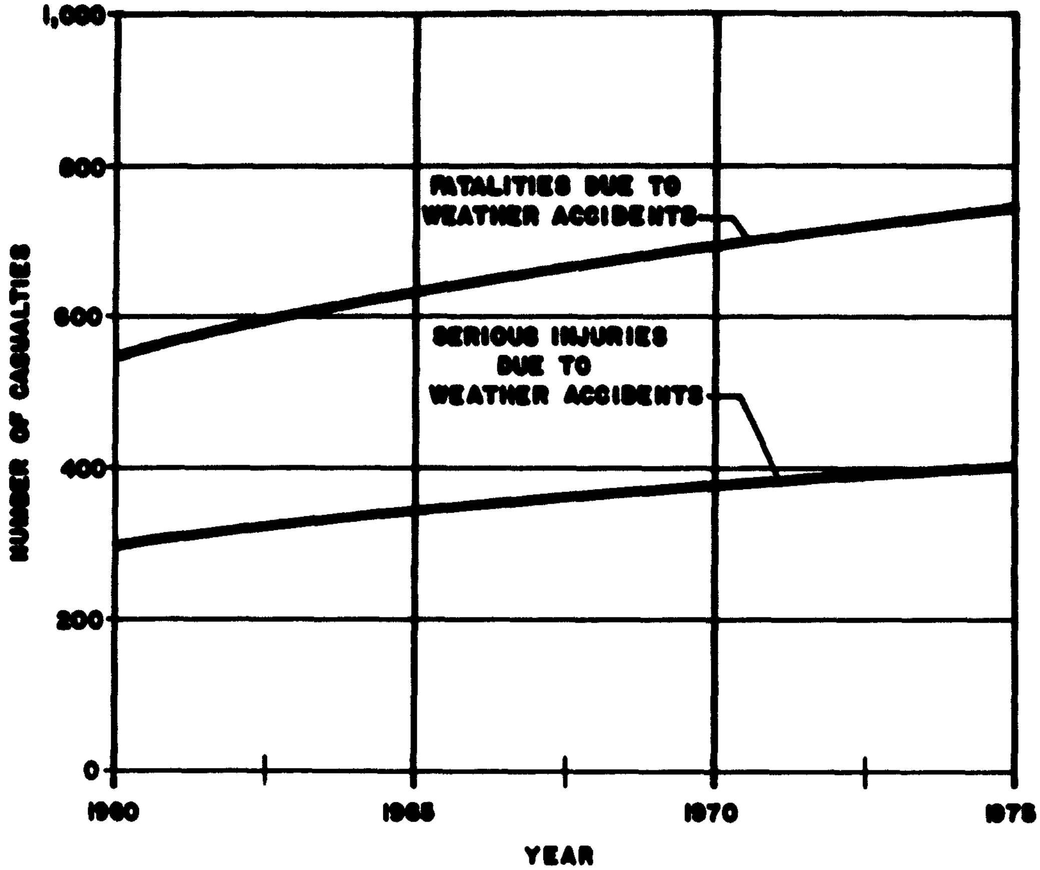

FIGURE 17. GENERAL AVIATION, PREDICTED NUMBER OF CASUALTIES DURING 1960-1975

Year	1960	1965	1970	1975
Minor Injuries	900	1020	1110	1200

d. **Summary**

The estimated numbers of fatalities, serious injuries, and minor injuries incurred in general aviation accidents due to weather causes are summarised as follows:

Year	1960	1965	1970	1975
Fatalities	550	630	690	740
Serious Injuries	300	340	370	400
Minor Injuries	900	1020	1110	1200

5. Cost of Casualties

To compute the dollar values of the penalties to general aviation due to weather, a clearer picture of the economic loss from an aviation fatality must be obtained. Although it may seem callous and materialistic to measure a fatality in terms of dollars, there is justification for this point of view since we are dealing with the loss to the national economy from these penalties. The moral and human loss and other intangibles cannot, of course, be evaluated but they are serious and important.

In considering the dollar loss incurred as the result of a fatality, one apparently reasonable approach is to treat life insurance payments or jury awards in cases of accidental death as a good approximation. The weakness of this approach lies in the fact that such dollar amounts consistute arbitrary limits governed by the amount of life insurance an individual can afford, or by the extent to which the individual can be considered liable or responsible for his own death, as well as by the claims that surviving family members may make in a law suit. Moreover, the law differs in the various states of the U.S. as to the maximum amount of recoverable financial loss due to a fatal accident. Thirty-five states have no upper limit of recoverable damages, while the remaining thirteen have limits ranging from a low of $20,000 to a high of $35,000.[1]

By way of illustration of the dollar value of the loss due to an aviation fatality, a typical jury award is cited:

Mildred G. Rogaw vs. U.S.[2]

Contribution to Family	$202,110 Total
Parental care and guidance	40,000 (2 children)
Funeral	877
	$242,987
Annual contribution that would have been made to family	$ 10,888

(The judge calculated that each $1000/yr income requires an investment of $18,713.91 at 3 1/2% interest. Therefore $10,888 would necessitate a sum of $202,110)

---

[1] Ref: "Best's Recommended Insurance Attorneys with Digest of Insurance Laws", Thirty-first annual edition 1959-1960.

[2] "Mildred Gottlieb Rogaw vs. U.S., May 25, 1959, Aviation Cases, Volume 6, 1958-1960", Published by Commerce Clearing House - Chicago 46.

a. Economic Loss from Aviation Fatalities

An aviation fatality generates an economic and a non-economic loss. The value of an individual's life to himself and his family is basically a non-economic one. Free men are not property or marketable assets. There is no market for human life or human grief. There is,however, an economic loss which can be estimated.

In this estimate we examine the following factors:

- Individual and Family
- Friends and Community at Large
- Employer
- Government

The average income of the pilots and passengers in a general aviation plane is estimated at $15,000 per year[1]. We have assumed an annual increase of 2.5% in salary, 40 as the average age at death and a discount rate of 6% per annum[2]. The 1960 value of this loss is $213,000[3]).

We have taken the present value of the individual's total income, rather than merely the segment devoted toward his family's personal consumption. The individual derives satisfactions from all uses made of his income. The allocation between personal and family uses is presumed to maximize his enjoyment of his income. The value of his assets at death is not included because the assets are not lost at death of the owner. Survivors will get subsequent benefit from the assets; thus there is no net loss to society.

---

[1]Three classes of general aviation flyers are identified. The 1960 income of business passengers was estimated at $20,000, private pilots, income at $13,000 instructors and professional pilots' income at $12,000. The weighted average income (by flying hours) is $15,000. per year for general aviation pilots and passengers of all categories.

[2]These figures are United Research, Inc. and Port of New York Authority estimates, using average salary and average age at death. Ref:"Economic Criteria for Federal Aviation Agency Expenditures", June 1962, FAA/BRD-355, pg. V152, and "New Yorks Domestic Air Travelers", Port of New York Authority, Aviation Dept. Oct. 1957.

[3]The rate of discount permits an evaluation at a given time of an income stream that occurs over a period of time. 6% is a rate that would apply to an individual in providing a future stream of payments.

For the purpose of assessing the net economic loss, we calculate the present value of the goods and services (income) the individual would have produced had he remained alive.

How this income would have been divided between the individual and his family does not affect this calculation. This total represents the minimum economic loss to society from the aviation fatality.

The loss to the family is both economic and non-economic. The economic loss to the family is a portion of the income referred to above. The non-economic loss to the family and the individual, should not be tied directly to the deceased's income. However, it may be linked to the total amount of money society is willing to pay to lessen the chances of an individual being killed.

Most people prefer to avoid a small chance of a large loss. This preference is expressed by taking out insurance even though the total premiums paid may exceed the amount of the potential losses. Policyholders generally are willing to pay more than the "fair price" of insurance in order to eliminate a small chance of a large loss.

Thus, to increase safety, most people would be willing to pay more than the strictly economic cost of the fatalities, aside from the emotional values involved. Increased safety reduces the risk (for themselves and others) of an aviation fatality. The amount each individual would be willing to pay (in taxes, or user charges) reflects his own evaluation of his risk (both economic and non-economic loss) and his preference to avoid such risk. In the absence of sampling surveys to estimate this amount, we have an uncertain value, a portion of which should properly be added to the economic loss computed below.

Loss to the Individual and His Family

The minimum loss from a fatality is the discounted value of the goods and services (income) the individual would have produced over the remainder of his life.

Loss to Individual's Friends and the Community

The surviving friends and the community at large suffer economic as well as non-economic losses. These are the satisfactions that the individual would have provided to friends and community by community and civic work, friendships, etc., had he lived. The fact that people would be willing to pay varying amounts to save the lives of friends points up the nature of this intangible value. We have arbitrarily assumed 15% of the individual's income as an approach to this intangible. The present value of this loss amounts to $32,000.

The Individual's Employer

The employer incurs the costs of finding and training a replacement and may suffer a further loss in the case of unique talents. A period of from 3 to 6 months is usually required to train a new man in a $15,000 position before the employer begins to receive appropriate returns on his investment. An average amount of $4500 is assumed to represent this loss.

The Government

Government accident investigation costs were assumed to be $1500 per fatality[1].

Total Estimated Economic Loss from an Aviation Fatality

The following table summarizes the estimated losses, from a fatality. In order to account for the rise in individual income in the 15 year period ahead, we assume a 2 1/2% annual income increment and 2% annual cost increases for government accident investigation.

Table 26. Estimated Economic Loss from an Aviation Fatality

	1960	1965	1970	1975
Individual and Famiy	$213,000	$241,000	$273,000	$309,000
Community and Friends	32,000	36,200	41,000	46,300
Employer	4,500	5,100	5,800	6,500
Government	1,500	1,700	1,940	2,200
	$251,000	$284,000	$321,750	$364,000

[1] U. R. I., op. cit, pg. VI-52. For government, employer, and community losses, we have used the estimates developed by URI in the interests of uniformity and in the absence of more exact data.

b. Costs of Serious Injuries

Some information on the dollar costs involved in injuries derived from general aviation aircraft accidents can be obtained from insurance companies which settle claims for such costs. Although no statistics are available which would produce an average cost of serious injuries, several statement can be made here that will be helpful in arriving at a reasonable figure.

Among the most frequent accidents leading to serious injuries are overturning and ground loops on landing and forced landings on all types of surfaces. An aircraft overturning on the ground or crashing in the process of a forced landing frequently produces head injuries in the passengers. If passengers are thrown out of the aircraft, internal injuries are most likely to occur in addition to broken arms and legs. Taking into account present costs of hospitalization per day, costs of operations, and costs of medical care, a figure of $2000 per serious injury as a result of an airplane accident is considered a conservative amount.

In addition, the loss of income of the injured person during the period of treatment must be considered. Although many individuals carry insurance covering loss of income, the amounts generally are less than the actual salary. A figure of $500.00 salary loss will be assumed. Thus, the average cost per serious injury will be taken as $2500.

c. Costs of Minor Injuries

These injuries as a rule do not require hospitalization. They come under the heading of cuts and bruises as well as shock. An average cost of $50 per minor injury is considered a reasonable figure.

d. Total Costs of Casualties

In summarizing the total estimated present and future dollar values of fatalities and injuries sustained in general aviation weather accidents we have used the projected values presented previously. Multiplication of unit costs by the number of predicted casualties yields the forecast dollar values set forth in Table 27 and Figure 18.

Table 27. **Predicted Total Costs of Casualties due to Weather Accidents (General Aviation)**

Item	1960	1965	1970	1975
Fatalities	550	630	690	740
Unit Cost	$251,000	$284,000	$322,000	$364,000
a. Total cost of fatalities	138,050,000	178,920,000	222,180,000	269,340,000
Serious Injuries	300	340	370	400
Unit Cost	$2,500	$2,500	$2,500	$2,500
b. Total cost of serious injuries	750,000	850,000	925,000	1,000,000
Minor Injuries	900	1020	1110	1200
Unit Cost	50.	50.	50.	50.
c. Total cost of Minor Injuries	45,000	51,000	55,000	60,000
Sum of a, b, & c (millions)	$138.85	$179.82	$223.16	$270.40

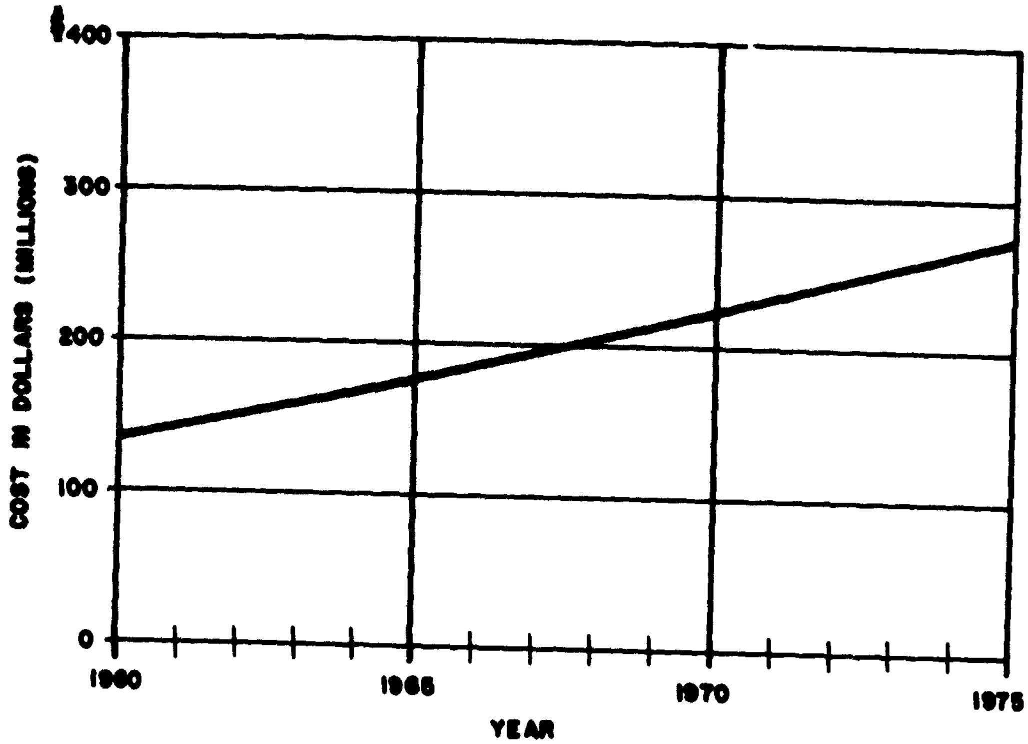

FIGURE 18. GENERAL AVIATION, PREDICTED TOTAL COST OF CASUALTIES DUE TO WEATHER ACCIDENTS

The table shows clearly the wide margin between the three types of casualties. Due to the fact that serious injuries number only one half the fatalities, and that their dollar value is only the 1/160th part of the estimated cost per fatality, their total is less than 0.3% of that of all fatalities. A similar situation prevails as between the categories of serious injuries and minor injuries, with the latter constituting only about 6% of the former.

From the foregoing it is quite apparent that fatalities have by far the greatest economic significance. In comparison, the cost of serious or minor injuries plays a lesser role. Thus, major emphasis should be laid on elimination of the causes leading to weather accident fatalities. According to the records fatal weather accidents occur most frequently when VFR pilots fly into IFR weather with which they cannot cope. A pilot takes off in VFR weather without filing a flight plan or obtaining a weather briefing. Within 50 to 100 miles he encounters unexpected weather conditions which require flying on instruments. Being untrained in IFR flight, he may lose control of his airplane and crash. Such crashes nearly always lead to fatalities.

Improvements in the availability, intelligibility, and use of weather information by general aviation pilots will undoubtedly make a major contribution to the safety of private flying. Since weather is the greatest single "killer" of general aviation pilots and passengers, the cost-benefit relationship of weather improvements will be especially significant here.

6. Aircraft Damage

a. Average General Aviation Aircraft

For the purpose of estimating the dollar value of aircraft damaged or destroyed, the age, type and cost of the typical average general aviation aircraft have been determined in this section.

On January 1, 1961 a total number of 78,760[1] active general aviation aircraft were registered with the Federal Aviation Agency. These "active" aircraft carry current airworthiness certificates which have been renewed within the past twelve months. FAA regulations require that all aircraft in flying status must have a periodic or progressive inspection at least once every twelve months, otherwise they are automatically classified as "inactive".

Out of the total number of active civil aircraft registered with the FAA, 49 percent were manufactured prior to 1950[2]. On the surface, this would indicate that most flying hours in general aviation are logged by aircraft about 5 to 10 years old. However, a check with aviation insurance companies reveals that this is not the case. Current estimates indicate that only 10% of all flying is done by these older aircraft licensed prior to 1950. Most of the flying hours are logged by more recent aircraft purchased within the last 2-3 years by business men and other private pilots. Therefore an average aircraft age of 3 years will be used for the purpose of this study.

A survey was made by the FAA of the various types of active general aviation aircraft for the years 1955-61 and projected to 1975. The results are presented in Table 28 below and plotted graphically in Figure 19. The graph shows that the single, four seater aircraft is rapidly becoming the most numerous type. According to statistics, it is also the one most frequently

---

[1] "Statistical Study of U. S. Civil Aircraft" as of January 1961. Statistics Division, Office of Management Services, Federal Aviation Agency

[2] Cited 1

Table 28. Number of Active General Aviation Aircraft in the Continental U. S. on January 1, 1955-61, Projected to 1965, 1970, 1975

Aircraft Class	1955	1956	1957	1958	1959	1960	1961	1965	1970	1975
Fixed wing										
Piston engine										
Single engine										
1-3 places	36,774	35,171	34,858	35,286	34,870	33,878	33,667	34,500	33,200	30,675
4 or more places	16,763	18,876	22,362	23,286	25,635	26,725	33,168	42,150	53,000	64,575
Multi-engine	2,605	3,283	4,113	4,956	5,327	5,918	7,031	9,500	13,300	18,100
Turbine engine										
Turboprop	-----	-----	3	4	5	20	98	300	400	500
Turbojet	-----	-----	-----	-----	-----	1	16	50	100	150
Rotary wing										
Helicopter	128	219	263	324	416	498	588	1,500	2,500	3,000
Autogyro	1/	1/	1/	1/	1/	5	8			
Gliders	184	216	243	247	277	307	359	1/	1/	1/
Balloons	13	13	12	12	14	16	11	1/	1/	1/
Dirigibles	2	2	2	1	1	1	1	2/	2/	2/
Total	56,469	57,780	61,856	64,116	66,545	67,369	74,000	88,000	102,500	117,000

1/ Included in 1-3 place single piston-engine fixed-wing class.

2/ Included in multi-piston-engine fixed-wing class

Historical data derived from reports of and information obtained from, Statistics Branch, Office of Management Services, Federal Aviation Agency.

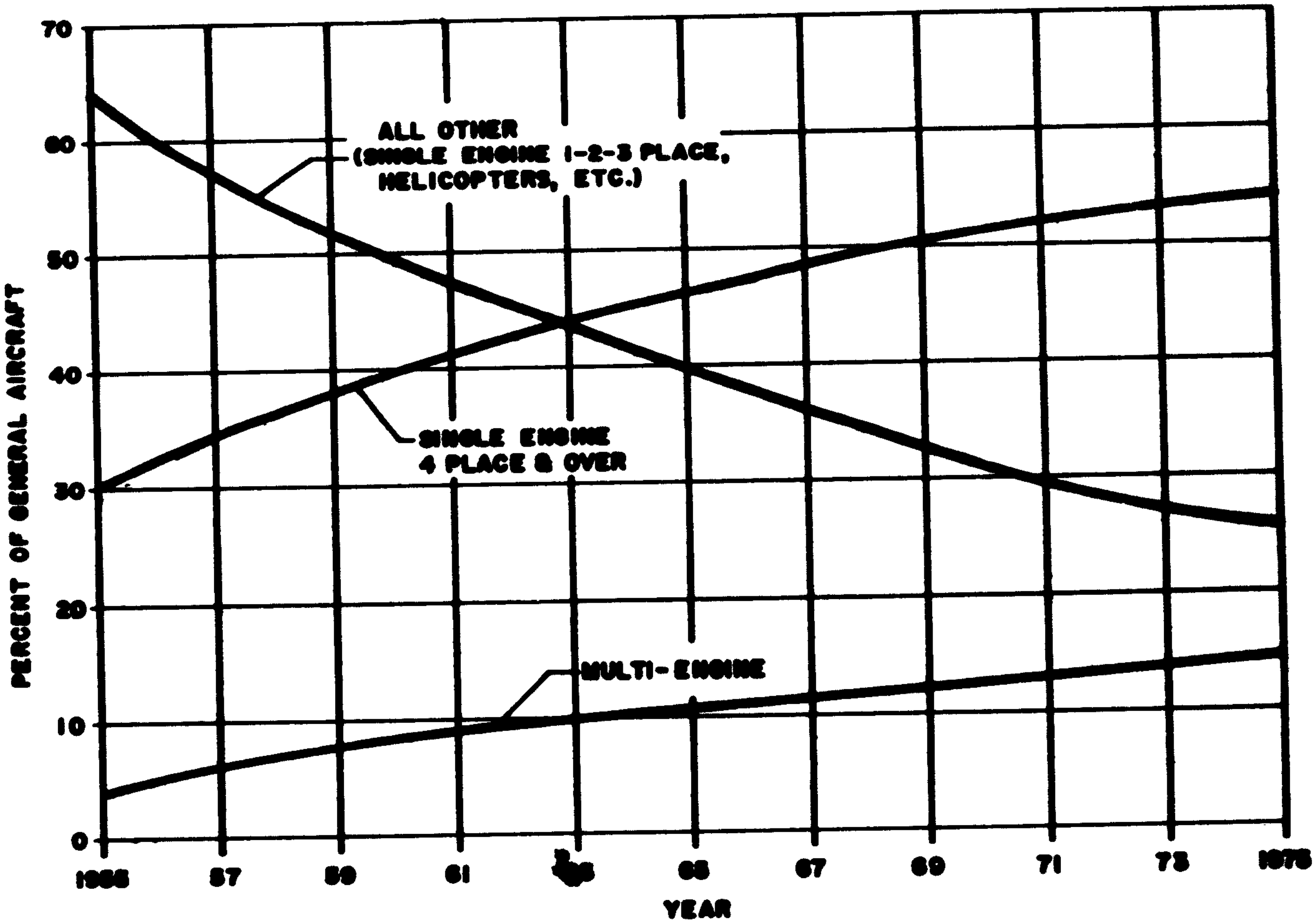

FIGURE 19. COMPOSITION OF GENERAL AVIATION AIRCRAFT FLEET
(PRESENT AND PREDICTED TO 1975)

REF: "AVIATION FORECASTS, FISCAL YEARS 1961-66," FAA, OFFICE OF PLANS, NOV. 1960

involved in weather accidents. Multi-engine planes, such as the twin engine Beech and Cessna types are generally flown by more experienced pilots who are less prone to become involved in accidents. Moreover, their more advanced navigational and communication equipment enables them to avoid a considerable portion of the ordinary weather flight hazards[1]. The graph, Figure 19 shows the distribution of the three main groups of general aviation aircraft:

Single engine, 1 to 3 place, and helicopters
Single engine, 4 place
Multi-engine, 4 place and over

The small 1-3 place, single engine types presently comprise about half of all general aviation planes but their trend is on the decrease. Moreover, they are likely to be of an older vintage than the more popular 4-place vehicles which show a strong uptrend and which are forecast to comprise over 55% of all general aviation aircraft in 1970, while 1-3 seaters will have dropped to 33%. The remainder, or 12% will be made up of multi-engine planes.

b. Aircraft Destroyed and/or Seriously Damaged

In order to estimate the number of aircraft that are likely to be destroyed and/or seriously damaged due to weather causes in the 15 year period ahead, use is made of available statistics. If the number of aircraft destroyed is examined for the period 1954 to 1959, for which detailed statistics have been compiled,[2] it is found that no clear trend can be recognized, from which a sound estimate could be made for the foreseeable future. On the other hand, if the number of aircraft destroyed is related to the total number of fatal accidents, an average constant factor of 2 is obtained. The curve of estimated number of aircraft destroyed in the 1960-1975 period, shown in Figure 20, is based on two aircraft destroyed for every fatal accident due to weather. In 1960,

---

[1] General Aviation Accidents (Non-Air Carrier) A Statistical Analysis, Calendar Years 1954-1957, and Statistical Review, General Aviation Accidents, Calendar Year 1959.

[2] Cited 1

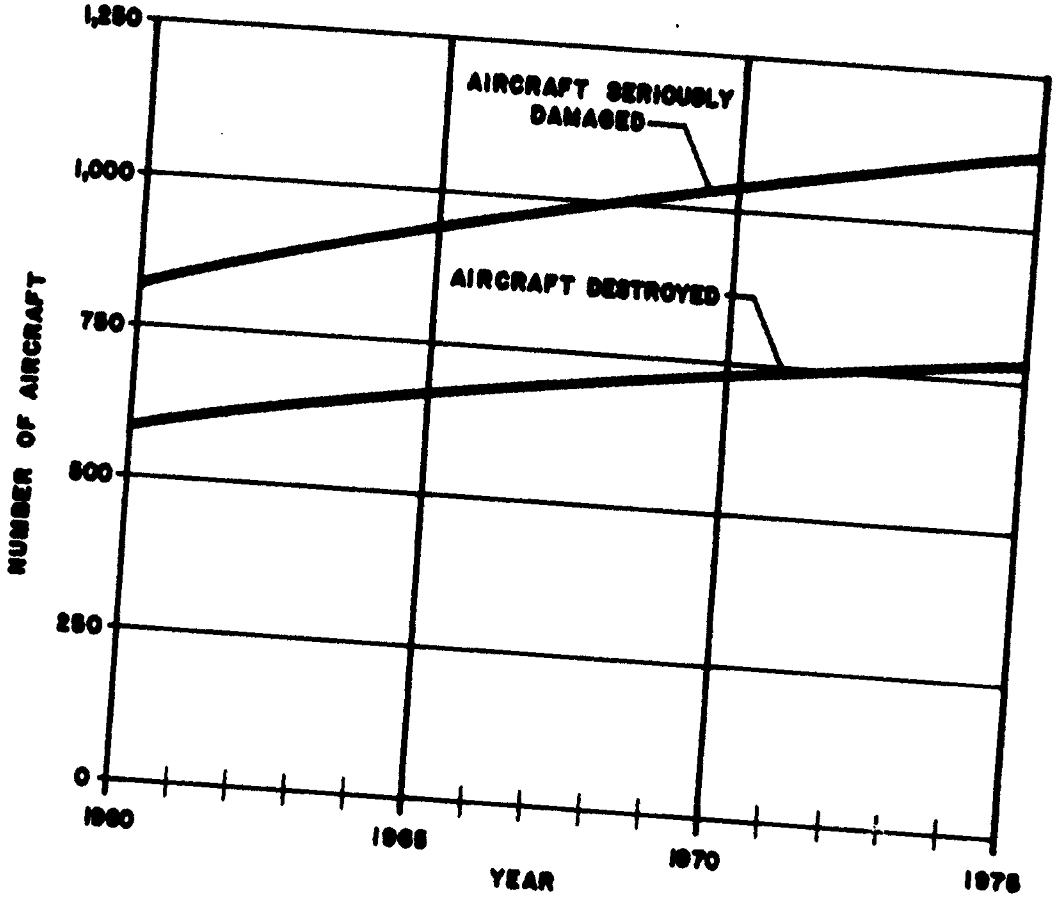

FIGURE 20. GENERAL AVIATION, PREDICTED NUMBER OF AIRCRAFT DAMAGED OR DESTROYED IN WEATHER ACCIDENTS

approximately 580 aircraft were destroyed in weather accidents, an estimated 660 will be destroyed in 1965, about 720 planes in 1970 and approximately 780 in 1975. The aggregate of these figures gives a round total of 11,000 general aviation aircraft expected to be destroyed in the next 15 years as a result of various weather causes.

In order to estimate the number of aircraft suffering substantial damage, use was made of the fact that accidents involving minor damage are not reported as a rule if no injuries or fatalities are involved. Therefore, the number of airplanes destroyed and those sustaining substantial damage make up the bulk of reported general aviation accidents; subtracting, then the number of aircraft destroyed from the total number of weather accidents yields the number of aircraft suffering substantial damage. Recent statistics prepared by the Safety Analysis Branch of the FAA, based on 1800 accident reports processed through July 31, 1961 show that the percentage of reported minor accidents is only on the order of 5% of all weather accidents. In view of this together with the low dollar values involved in minor damage accidents as compared to the costs of serious accidents, this category has been included in the cost of seriously damaged aircraft. In estimating the number of aircraft suffering substantial damage, therefore, the difference between forecasts of total weather accidents and of number of aircraft destroyed was computed. This method was tested and checked out on the actual recorded numbers during 1954 to 1959.

The projection of substantially damaged general aviation aircraft in weather accidents within the 15 year period ahead is presented below:

Year	1960	1965	1970	1975
Aircraft with Substantial Damage	820	940	1040	1120

These values have been plotted in Figure 20.

c. Value of Average Aircraft

In computing the value of a destroyed airplane, depreciation must be taken into account, together with the fact that many new aircraft owners add from 20% to 50% of the aircraft's cost in navigation and communications equipment during the first 2-3 years. The depreciation percentage has been fairly constant over the last 20 to 30 years. A value of 12% per year on the remaining value is used by aviation insurance underwriters. To arrive at a cost value per airplane destroyed the following tabulation of the prices of current general aviation aircraft has been compiled.

Table 29. Prices of General Aviation Aircraft, 1961

Model	Engines	Seats	Gross Weight Pounds	Approximate Price in Dollars
A. Beech Aircraft				
A33 Debonair	1	4	3000	21,750.
N35 Bonanza	1	4	3125	26,500.
B95A Travelair	2	5	4200	49,500.
55 Baron	2	5	4880	58,250.
D50E Twin Bonanza	2	6	6300	87,250.
65 Queen Air	2	6	7700	126,000.
Super G18	2	6	9700	132,300.
B. Cessna Aircraft				
172	1	4	2200	13,000.
175	1	4	2350	16,000.
182	1	4	2550	20,000.
210	1	4	2900	25-30,000
Skywagon	1	6	2900	35-40,000
310F	2	4-5	4900	65,000.
C. Piper Aircraft				
Colt 108	1	2	1660	5,000.
Cherokee 150	1	4	2150	9,800.
Cherokee 160	1	4	2200	10,000.
Comanche 180	1	4	2700	16,500.
Comanche 250	1	4	2800	20,500.
Apache G	2	4-5	3800	34,000.
Aztec	2	5	4800	53,000.

An analysis of the above tables shows that the average purchase price of a 4-place, single engine airplane is $19,000. This agrees with insurance company statistics which indicate that aircraft most frequently involved in accidents are single engine planes in the $16,000. to $20,000. price class.

Allowing for the fact that the average age of the aircraft involved in accidents is 3 years, depreciation would reduce the value to $11,200. Adding in navigational and other equipment a very conservative figure of $12,500. is derived as the value of the average 4-place, single engine aircraft involved in a weather accident.

The smaller, single engine planes, seating less than 4 persons, range in price from $5000 to $10,000. Taking into account an average price of $7500, three years of depreciation and a certain amount of equipment purchased, an average value of $5000 appears to be a conservative figure.

A relatively small number of multi-engine aircraft is presently in service[1]. In this category are the light, twin engine aircraft listed above, as well as the heavier twins over 12,500 lbs such as the DC-3 B-26, Convair and Gulfstream. An average value for this aircraft type, including a 3year depreciation and its additional equipment will be assumed here as $60,000. This is a conservative estimate in view of the fact that the heavier twin engine aircraft are all in the $100-200,000 class and over.

---

[1] Only about 1000 aircraft of the latter four types are currently operational while the total number of multi-engine planes amounts to 7000 out of approximately 70,000 general aviation aircraft. Ref: "Aviation Forecasts, 1961-1966, (FY) FAA.

7. Total Cost of Aircraft Damaged and/or Destroyed

In order to determine the total cost of general aviation aircraft destroyed or severely damaged in accidents due to weather causes, the average computed values of the three typical types of private and corporate aircraft are being used. Estimated total costs for the years 1960, 1965, 1970 and 1975 have been computed in Table 30 and presented graphically in Figure 21.

The following average costs have been used:

Type	Value
Single Engine, 1-3 seats	$ 5,000
Single Engine, 4 seats	$12,500
Multi-engine	$60,000

GENERAL AVIATION

Table 30. Predicted Total Costs of Aircraft Damage Due to Weather Accidents

Item		1960	1965	1970	1975
Total number of aircraft destroyed		580	660	720	780
Single Engine 1-3 Seats	Percent of Total, Fig. 19	52%	41%	33%	28%
	Number	300	270	237	219
	Avg. Cost Per Aircraft	\$5,000	\$5,000	\$5,000	\$5,000
a)	Total Costs	\$1,500,000	\$1,350,000	\$1,185,000	\$1,095,000
Single Engine 4-Seats	Percent of Total, Fig. 19	39%	48%	55%	59%
	Number	226	316	395	461
	Avg. Cost Per Aircraft	\$12,500	\$12,500	\$12,500	\$12,500
b)	Total Cost	\$2,830,000	\$3,950,000	\$4,930,000	\$5,750,000
Multi-Engine	Percent of Total Fig. 19	9%	11%	12%	13%
	Number	54	74	88	100
	Avg. Cost Per Aircraft	\$60,000	\$60,000	\$60,000	\$60,000
c)	Total Cost	\$3,240,000	\$4,440,000	\$5,280,000	\$6,000,000
Number of Aircraft Sustaining Substantial Damage		820	940	1,040	1,120
Average Cost of Damage		\$5000.	\$5000.	\$5000.	\$5000.
d)	Total Cost	\$4,100,000	\$4,700,000	\$5,200,000	\$5,600,000
Sum of a, b, c & d (million)		\$11.67	\$14.44	\$16.60	\$18.45

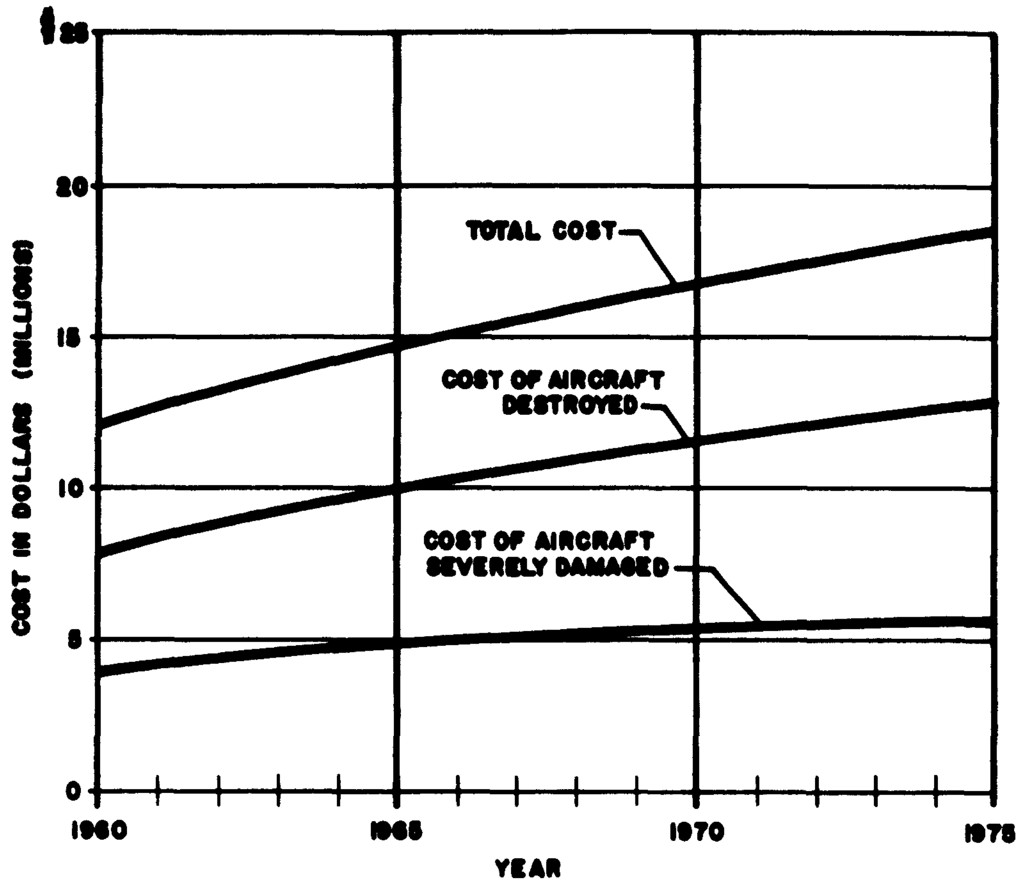

FIGURE 21. GENERAL AVIATION, PREDICTED TOTAL COSTS OF AIRCRAFT DAMAGE DUE TO WEATHER ACCIDENTS

8. Delays Due to Weather

a. Estimated Hours of Delay

1) Total Weather Delay

To obtain a measure of the total delay incurred by VFR general aviation flights[1] the climatology of terminal weather of less-than-VFR conditions was examined. A study[2] based on 3 years of hourly weather observations for 21 terminals distributed through the contiguous United States reveals that terminal conditions were less than VFR 9.28% of the time. Considering that airports are usually situated in the lower terrain areas, and in locations where the weather is most favorable over a specific area, it has been assumed that enroute conditions are below VFR at least twice that often or 18.5% of the time. Thus, general aviation VFR activity will suffer some kind of delay because of weather conditions approximately 18.5% of the time. If we project this percentage over itinerant VFR flights numbering a total of 6.9 million in 1960, then 1.28 million of these flights were affected by some kind of weather delay.

On an enroute basis, assuming that the flight is able to circumnavigate the less than VFR condition in an average of 10 additional minutes, the 1.28 million flights would experience a total delay of 0.213 million hours. On a terminal weather basis, 9.28% or 0.64 million flights were affected. If we assume that each flight was held up for an average of one hour on departure[3] and 15 minutes on arrival, a delay of 0.8 million hours is involved. The total delay due to weather, incurred by VFR itinerant general aviation flights therefore is estimated at 1.013 million hours in 1960.

---

[1] (IFR Flights have been treated under ATC Delays, Part IC.)

[2] "Quantitative Assessment of the Performance Characteristics of the Airways Terminal Forecasting System", Aerometric Research, Inc., 1962

[3] When the weather conditions do go below VFR minimums the condition normally persists for a number of hours.

There are no statistics available on the delays experienced by VFR general aviation flights due to incorrect weather information. In order to arrive at a reasonable estimate the study by Aerometric Research, Inc. [1] has been used to obtain percentage figures as to the correctness of forecasts which affect general aviation VFR activity. For our purpose the accuracy of 3 hour and 6 hour forecast accuracies were examined.

When the 3 hour terminal weather forecast specifies conditions equal to or better than VFR minimums, the forecast is incorrect 4.6% of the time. The corresponding figure for the 6 hour forecast is 5.5%. The average for the two forecasts is thus around 5%. However, since better than VFR minimum conditions are forecast about 92% of the time, the actual percentage is 4.6%.

When less than VFR conditions are forecast incorrectly, flights that are VFR only will be cancelled. It is not possible to accurately estimate the frequency of such occurrences. Based on the accuracy percentages of less than VFR forecasts, however, (the forecasts are incorrect about 40% of the time and IFR conditions occur about 9% of the time) some 200,000 flights are estimated to be cancelled for this reason.

When VFR or better is forecast incorrectly, the user can be affected in various ways.

a) User proceeds to airport-is delayed on the ground when departure terminal forecast proves incorrect.

b) User departs - suffers enroute delay:

(1) circumnavigates

(2) uses enroute alternate terminal for landing

(3) returns to departure airport

---

[1] Cited 2, pg. 121

c) User proceeds to destination airport area and is delayed over or near destination:

(1) diverts to alternate

(2) holds and lands after improvement

(3) returns to departure airport

In case a) the user may wait on the ground for some period of time awaiting weather improvement. The penalty is a passenger time loss. Since weather ordinarily exhibits substantial persistence, this type of delay may easily amount to an hour or more.

Based on the average accuracy of the 3 and 6 hour forecasts in 1960, the 6.9 million itinerant VFR general aviation flights[1] would have experienced 320,000 hours of departure delay. Due to the numerous assumptions used in this estimate and the resulting uncertainties, this value will not be included as a weather penalty.

In case b), enroute delays, the delays involved in landings at alternate terminals and returning to the departure airport are estimated at an average of 2 hours. Applying the estimate that 5% of forecasts will be incorrect, we obtain an estimated 128,000 hours of enroute delays for the 1.28 million flights. This loss must be computed both in terms of direct operating costs and in loss of passenger time.

In case c) delays at destination, an average delay of 2 hours was assigned to diversion, hold/land, and return, respectively. Thus, the 1960 delay would have been 128,000 hours affecting both passenger time and direct operating costs.

The sum of b) and c), 256,000 hours, delay has been rounded off to 200,000 hours in 1960 involving both loss of passenger time and direct operating expenses.

[1] FAA, Forecasts of Air Traffic Activity, CONUS 1960-1975

b. **Direct Operating Costs**

The costs associated with general aviation weather delays, as analyzed in the following sections, are divided into direct operating costs of the aircraft and loss of passenger time. The estimated direct operating costs for VFR itinerant general aviation aircraft are shown in Table 31. They are slightly less than those for IFR aircraft due to the fact that VFR equipment is generally in the lower power class. The table weighs the costs according to total hours flown by the various types of aircraft. The hourly direct operating costs of these types are averages derived from quoted costs of several aircraft dealers.

Table 31. Average 1960 Direct Operating Costs for Itinerant VFR General Aviation Aircraft

Aircraft Class	Hours Flown[1] Thousands	% of Total	Cost/Hour[2] Dollars	Proportional Cost-Dollars
Single-Engine				
1-3 place over 100 h.p.	1302	14.0	14.00	2.00
4 place up to 200 h.p.	2904	31.4	20.00	6.30
over 200 h.p.	2867	31.0	30.00	9.30
Multi-engine up to 800 h.p.	1272	13.6	55.00	7.50
800-2000 h.p.	457	5.0	80.00	4.00
over 2000 h.p.	460	5.0	130.00	6.50
Average Cost/Hour				35.60

[1]FAA Statistical Handbook of Aviation, 1961 Edition

[2]Estimates from quoted dealer costs

Based on the estimated hours of delay due to lack of or inadequate weather information, the itinerant VFR general aviation activity suffered a loss of 200,000 hours x $35.60 or $7,120,000 in 1960. Extrapolating on the basis of FAA's activity forecasts[1], the costs would be:

Item	1960	1965	1970	1975
Total Hours	200,000	245,500	288,000	322,000
Operating Costs per Hour	$35.60	$35.60	$35.60	$35.60
Total Estimated Operating Costs (millions)	$ 7.12	$ 8.74	$10.25	$11.46

c. Loss of Passenger Time

It was established from Federal Aviation Agency statistics that the average number of passengers per aircraft in 1960 was 3.3. The Agency forecasts 3.9 per aircraft in 1965, 4.2 in 1970 and 4.8 in 1975.

The value of the time of the passenger on an itinerant VFR flight is estimated to be $8.40/hour for 1960. This was derived by assuming that that single engine 1-3 place over 100 h.p. aircraft and the 4 place up to 200 h.p. aircraft carry personnel who earn $9,000 to $13,000 yearly (an average of $11,000).

Assuming an annual growth rate of 2 1/2%/yr., the passengers time will be worth:

in 1960	$8.40
in 1965	$9.50
in 1970	$10.75
in 1975	$12.20

[1] FAA Forecasts of Air Traffic Activity, 1960-1975

Using FAA forecasts of passengers per aircraft, the estimated delay in hours incurred because of incorrect weather information, and the estimated value of the passengers' time, a loss of 200,000 hrs. x 3.3 passengers x $8.40/hour, or $5,544,000 was suffered in itinerant VFR operations in 1960.

Table 32 shows the estimated costs due to loss of passenger time in the 1960-1975 period.

Table 32. Estimated Costs of Lost Passenger Time

Item	1960	1965	1970	1975
Total Hours of Delay	200,000	245,000	288,000	322,000
Number of Passengers	3.3	3.9	4.2	4.8
Total Hours of Passenger Time Lost (millions)	0.660	0.955	1.210	1.540
Cost per hour of passenger time	$8.40	$9.50	$10.75	$12.20
Total Cost of Passenger Time Lost (millions)	$5.55	$9.10	$13.00	$18.80

d. Loss of Utilization

It was assumed that all general aviation aircraft suffering control delays were business or commercial aircraft. The loss of utilization for a business (or executive) aircraft owned by a company or an individual differs from that for a commercial for hire aircraft in that the loss of utilization of the former primarily affects future appointments while the loss of utilization of the latter is measured in terms of direct net operating revenue.

Straightforward costing of the "for hire" aircraft is possible but has been taken into account under direct operating costs.

The cost of delay associated with loss of utilization hours incurred by business aircraft is not readily assessible. In, perhaps, 95% of the cases where an aircraft is delayed, no real loss of utilization is suffered. In the remaining cases, the loss of a day's time by one or more executives or salesmen or the loss of a contract, may be involved. The cost associated with this kind of utilization loss may be of considerable magnitude but there are no statistics which can be employed in calculating it. Therefore, no estimate of these losses has been made here.

9. <u>Diversions and Cancellations</u>

a. Occurrence of Diversion and Cancellations

The diversions and cancellations incurred by IFR general aviation are assumed to be directly proportional to those of the air carriers. Since general aviation IFR activity is small as compared with VFR operations, the resulting numbers of diversions and cancellations during IFR flights are negligible.

The diversions and cancellations incurred by itinerant VFR general aviation activities can be calculated in a manner similar to that used to determine the delay factor. Using the basic figures previously employed some 64,000 flights suffered a diversion in 1960, and some 320,000 flights were delayed at point of origin. Of these latter, it is conservatively estimated that 10% were cancelled. Therefore, there were 64,000 diversions and 32,000 cancellations suffered by itinerant VFR general aviation in 1960 as a result of incorrect weather information.

Using FAA traffic estimates of expected VFR traffic there will be 78,000 diversions and 39,000 cancellations in 1965, 92,000 and 46,000 in 1970, and 104,000 and 51,500 in 1975.

b. Cost of Diversions due to Weather

The direct operating costs and passenger time losses associated with diversions were partially taken account of in the discussion of delays. That is, the operating cost involved in circumnavigation, flying to an alternate terminal or returning to destination was considered. The portion not previously counted is associated with the continuance of a flight which landed at an alternate terminal. These flights, unless the alternate terminal was directly on the intended flight path, are required to cover extra distance to reach the destination. If it is assumed that the average diversion takes place 100 miles short of destination and that the alternate terminal is 20 miles away from the intended line of flight, the added cost is so small as to be negligible.

c. **Cost of Cancellations**

There is no direct operating cost associated with cancellations but it may logically be argued that cancellation of a flight can be costed in terms of passenger time loss. A business man delayed in leaving or returning to his base of operations frequently loses valuable time that could be spent in additional business pursuits. If he cancels a flight from his home base there is a loss involved in the time spent in going to the airport and in returning if this time is not utilized for business discussion. Moreover, a loss of potential business is frequently suffered. Such losses are possible to assess only if adequate data are available. Since such statistics are lacking, they have not been taken into account here.

10. **Summary of Total Penalties**

The total projected costs of the penalties incurred by general aviation due to weather causes are presented in Table 33.

Table 33. General Aviation - Estimated Costs of Penalties Due to Weather Causes (Millions)

Item	1960	1965	1970	1975
A. Casualties	$138.85	$179.82	$223.16	$270.40
Fatalities Serious Injuries Minor Injuries				
B. Aircraft Damaged and/or Destroyed	$11.67	$14.44	$16.60	$18.45
C. Delays	$12.67	$17.84	$23.25	$30.26
Sum of A, B, & C	$163.19	$212.10	$263.01	$319.11

PART I

PENALTIES DUE TO WEATHER

C. THE AIR TRAFFIC CONTROL SYSTEM AND ITS USERS

1. Introduction

2. General Use of Weather Information by the ATC System

   a. Control System Components
   b. The Significance of Weather Information to the ATC System

3. Total Penalties Incurred

   a. By the Control System

      1) Duplication in the Controller's Workload
      2) Measure of Loss of Efficiency and Resultant Penalty

   b. By the Air Carriers

      1) Estimated Hours of Delay
      2) Economic Loss Associated with Delayed Hours and Direct Operating Costs
      3) Economic Loss Associated with Delayed Hours and Lost Passenger Time

   c. By the General Aviation

      1) Estimated Hours of Delay
      2) Economic Loss Associated with Delayed Hours and Direct Operating Costs
      3) Economic Loss Associated with Delayed Hours and Lost Passenger Time

   d. By Military Aviation

      1) Estimated Hours of Delay
      2) Economic Loss Associated with Delayed Hours and Direct Operating Costs
      3) Economic Loss Associated with Delayed Hours and Lost Passenger Time

   e. Summary of Total Penalties

4. Penalties from ATC Delays due to Weather Causes

PART I

C. THE AIR TRAFFIC CONTROL SYSTEM AND ITS USERS

C. AIR TRAFFIC CONTROL SYSTEM AND ITS USERS

1. Introduction

Due to the nature of the data available for analysis, the approach in this section has been first to estimate the total economic penalties from all causes incurred by the ATC system and its users, the air carriers, general and military aviation, and, secondly, to make a reasoned estimate as to that portion of the total penalty which can be ascribed to weather causes.

The final step, estimating the portion of the total weather caused penalties due to lack of or inadequate weather information, and hence susceptible to improvement, is presented in Section III, B. 6.

2. General Use of Weather Information by the ATC System

The main function of the Air Traffic Control System is to promote the safe, orderly and expeditious flow of all air traffic. The use of weather information, including its prompt receipt and dissemination to the pilots and to the ATC system, plays an important part in this function. Current disruptions of the smooth and efficient functioning of the Air Traffic Control System are not so much due to adverse weather as to the inability of the system to receive and use timely operational weather information, and to pass it on to the pilot in the air, especially during critical weather periods. The ATC system now merely reacts to bad weather after it has occurred and attempts to adjust to adverse weather conditions on an emergency basis rather than planning its schedules, work load, and activities through the optimum use of advance operational weather inputs.

a. Control System Components

A brief discussion of the control units, through which delays due to weather conditions are initiated, is given below.

- **Airport Traffic Control Towers** - These are located at airports in terminal areas. The towers control arriving, departing, and local traffic. There are approximately 450 control towers in the U.S. operated by the FAA, the Military and in some cases by municipalities.

- **Air Route Traffic Control Centers** - These units have a primary requirement for enroute weather information, but may also utilize terminal information. Flight weather and wind information is needed for route path and altitude selection and time estimates, approach stack, and altitude choice. There are a total of 29 centers in the contiguous U.S.

The map in Figure 22 shows the outlines of the areas served by these centers as well as the cities in which the centers are located.

- **Flight Service Stations** - These units are not considered here since they are not involved in the delay aspects of the system. However, these units have an important need for accurate, timely weather information for use in advising and briefing pilots.

b. The Significance of Weather in the Air Traffic Control System

Weather information is needed by the control system in its task of implementing the safe and orderly flow of air traffic. The activities directly influenced by the weather and which can be optimally planned through the use of adequate weather information cover the entire ATC range.

- **Enroute Flow Planning and Progress Estimating** requires advance knowledge of the locations, intensities, development and/or movement of hazardous conditions as well as the winds.

Figure 22. ATC Enroute Centers

- <u>Control of Traffic on the Airport Surfaces</u> requires advance knowledge of changes in wind direction, gusty wind conditions, and visibility. Current information of surface accumulations and the type of accumulations is of value.

- <u>Control of Local Traffic</u> requires a knowledge of ceiling, and visibility, and surface winds as well as advance information of changes expected in ceiling, visibility, and surface wind conditions. Advance information of the approach of thunderstorms, in addition to being an absolute requirement in the interests of safety, can also contribute to a reduction of delays through a re-ordering of the traffic flow.

- <u>Control of Departing Traffic</u> requires a knowledge of icing and turbulence areas, cloud bases, tops, amounts, and winds aloft. The existence of such hazards will require the departing traffic to have alternate routes and altitudes available for possible re-routing. Reduced ceilings and visibilities in the departure areas will affect the rate at which the controller will issue take-off clearances. Vertical separation standards are increased from 1000 to 2000 feet when severe turbulence is known to exist.

- <u>Control of Approaching Traffic</u>, which may be accomplished by the center and the tower, or the tower alone, requires adequate weather information to minimise delay. Both terminal conditions and conditions aloft are of importance. Impending fluctuations of ceiling/visibility through critical values and changes in surface wind need to be known to allow the controller to reorder traffic on a capability basis and to reorder flow patterns. Knowledge of icing and

turbulence areas, and their movement allows optimisation of aircraft movements in the approach and holding patterns. Delays, due to weather-caused lowering of airport acceptance rates, are increased appreciably when aircraft in the holding patterns are forced to contend with very unfavorable flight conditions[1]. An accurate knowledge of slant range visibility on the glide slope materially reduces missed approaches and thus contributes significantly to delay reduction. The same comment applies to the winds on the glide slope and particularly to low altitude shear zones which are known to exist but are not currently observed or forecast.

[1] Chicago Area Air Traffic Flow and Delay Analysis, Contract FAA/BRD-42, Cook Research Labs., Sept. 15, 1959.

3. Total Penalties Incurred from All Causes

a. By the Control System

One of the principal factors affecting the Air Traffic Control System in achieving its goal of "safe and efficient utilization of the airspace" is the present inability of the system to obtain and use timely, accurate and operationally oriented weather information. The sudden impact of deteriorating weather conditions over a portion of the airways frequently finds the system operating with a full fair-weather load of airplanes. The immediate result of such a situation is a decrease in acceptance rates, or in the extreme case, a closing of one or more terminals in the affected area. This requires the initiation of flow control, establishing of holding patterns and possibly diversions, all of which cast a sudden, large overload on the controllers. If the affected terminals are major hubs, the effects on traffic flow soon spread outwards in all directions for hundreds of miles to other control areas.

If such a weather situation also involves turbulence, the reduction in traffic capacity is even greater. Vertical separation between aircraft in the turbulent areas must be doubled, from 1,000 to 2,000 feet, thus eliminating a number of flight altitudes. Re-assignment of available altitudes and/or re-routing of aircraft imposes an additional workload on the controllers. Moreover, moderate to severe icing conditions will render a range of altitudes unusable around and/or over the affected area.

The response time of the present aviation weather service is inadequate to react to and issue advisories regarding short-period, operationally significant weather changes. Normal communication channels can take up to 90 minutes to deliver a significant pilot report, which may be the first and only clue to the existence of a deteriorating weather situation, and under existing conditions may never even be disseminated. Additional time is required to digest the report, and for preparing and transmitting a forecast amendment. Yet the operationally critical time period of revised information is from a few minutes, in the case of an imminent landing or take-off, to around three hours for a briefing in preparation for an average flight.

Thus, it is apparent that a severe case of air traffic "indigestion" can develop during the time interval required for the present aviation weather service to ascertain the existence of deteriorating weather conditions, process the information, and issue revised forecasts. Presently, only a small portion of the pilot reports received by flight service stations are utilized in improving and updating approach zone weather information.

The result of this situation is that the Air Traffic Control System suffers large penalties in efficiency and capacity due to hedging procedures and additional safety factors introduced for the purpose of "wiring around" the weather, many of which could be eliminated if the response time of the weather service could be reduced to the point where information regarding significant short-period weather developments could be delivered to the Air Traffic Control System in time to be of operational use.

The long range goal of any weather service which supports the control system should be the issuance of advisories concerning weather deterioration <u>before</u> the fact. In the interim period, rapid recognition of deterioration and immediate forecast revision is of course vital.

1) <u>Duplication in the Controller's Workload</u>

A large portion of the Air Traffic Controller's work consists of the issuing of IFR flight clearances, preparing of flight strips by posting estimated times of arrival at the various check points, and searching for conflicts with other aircraft in the air. Additional tasks of the controller may be any one or combinations of the following in case of unexpected weather phenomena: initiating of flow control, issuing of holding instructions to keep aircraft at proper spacing intervals, instituting proper holding patterns, updating or correcting initial postings in case of late or early arrivals at check points.

In the performance of these duties the controller would be greatly aided by a detailed and accurate knowledge of existing weather

conditions and by accurate forecasts, both long term for advanced planning (traffic and/or personnel utilisation) scheduling purposes, short term for proper guidance of incoming/departing pilots, and for decision-making in the control of local traffic.

Under present conditions, however, the controller at the Air Traffic Control Center ordinarily cannot make full use of available weather information. He does not see all weather hazards, such as precipitation centers or squall lines, on his traffic surveillance radar nor does he receive weather observations and forecasts in the degree of detail and timeliness that he requires.

Thus, lack of use of weather information introduces a considerable element of inefficiency into the controller's work. A specific example of a flight plan change due to weather will illustrate this point:

- Pilots in the air who encounter adverse weather conditions which were not forecast or which were unknown to the controller when a flight plan was issued, usually request a change in flight plan.
- Before assigning a new altitude to the pilot, the controller must perform a time-consuming conflict search.
- If no conflict at the new altitude or on the new route exists, a new flight plan is issued by the controller, involving additional postings and time.
- In cases of severe turbulence, the required vertical separation must be increased from 1000' to 2000', requiring an additional search by the controller to effect the new 2000' separation between aircraft in the area of turbulence. This reduces the available airspace and creates an added burden at a critical period.

2) <u>Measure of Loss of Efficiency and Resultant Penalty</u>

A measure of the total workload of the ATC function can be obtained from the number of contacts required, number of flight plans processed, the number of postings made, the number of flight plan changes, the number of updates required, and the number of pilot requests for special weather information. This last item is distinctly separate from the others, having no relationship to the controller's primary duties. However, it can materially add to the communication load and thus delay control messages. It also consumes controller time, resulting in delays in the control decisions.

Figure 23 indicates in schematic fashion the processing of a flight plan from the filing to the closing but the figure assumes that changes in the flight plan are either due to the controller's request (traffic conflict) or due to the pilot's request (almost entirely due to weather factors).

Each operation, including postings on the part of the controller from pre-planning the individual flight to the actual arrival and close-out of the flight plan, is considered a "transaction" and is assumed for this study to represent that fraction of the over-all workload of the controller imposed by the processing of the flight plan and the controlling of the flight.

The FAA Air Traffic Activity report for 1960[1] indicates that a total of 3,687,000 IFR flight plans were filed. Recording of fix postings was discontinued after 1959 but the posting averages for 1959 can reasonably be applied to the 1960 figures. Using the average number of transactions per IFR flight (10.5) for 1959, a total of 38.7 million transactions is estimated for 1960. These include all weather-induced and traffic-induced flight plan changes as well as routine progress reports. It will be noted (Figure 23) that the number of enroute progress reports, namely 31,326,000, was computed by subtracting take-off and landing transactions from the total number of 38.7 million.

[1] FAA Air Traffic Activity, Fiscal Year 1960

Figure 23 . Schematic Diagram of Flight Plan Processing

PILOT ACTION	CONTROLLER ACTION	NO. OF TRANSACTIONS 1960
Pilot Files Flight Plan Estimates Departure Time	Personal Contact or Telephone via FSS, Tower	
	Controller Alerted, Posts Flight Plan, Prepares Clearance	3,687,000
Pilot (or tower) Notifies Controller of Taxi or Departure Time		
	Controller Receives Departure Time, issues Initial Clearance to Pilot	3,687,000
Pilot (or tower) Notifies Controller of Actual Lift-off Time		
	Controller Receives Lift-off Time, Posts Flight Plan	3,687,000
Pilot Reports Progress Points and Estimates		
	Controller Receives Progress Reports, Updates Flight Strip	31,326,000
Pilot (or tower) Reports Time of Arrival		
	Controller Closes Flight Plan	3,687,000
Total Transactions of Actual Work Load: (including changes)		46,074,000

From a comparison of the actual enroute transactions executed, including flight plan changes, with the transactions with no updates or changes in flight plans, the additional workload imposed by flight plan changes on the ATC system can be estimated.

To determine the theoretical number of transactions required with no changes in flight plan, the average trip distance and the minimum number of postings required per flight must be estimated.

The average distance for propeller-driven and turbojet aircraft is estimated from the FAA forecast of air traffic activity[1] for 1960 by weighting the daily aircraft utilization with the average speed and numbers of aircraft involved to give the following weighted average distances:

	Average time	Average speed	Average trip distance
General Aviation	1.10 hrs.	130 kts.	142 miles
Air Carrier, Propeller	.95 hrs.	226 kts.	215 miles
Air Carrier, Jet.	3.7 hrs.	471 kts.	1730 miles

Based on these mileages, the minimum number of transactions per trip with no updates or changes is estimated to be 9 for turbojet aircraft and 3 for the propeller aircraft. Applying 9 transactions to the 711,000 turbojet flights and 3 transactions for 2.52 million propeller IFR flights, the weighted average is 4.6 postings per flight. This includes take-offs and arrivals for general aviation, air carrier, and military IFR flights and results in a total figure of 16.9 million postings. Deducting the take-offs and landings we arrive at the theoretical enroute number of postings of 9,526,000.

The difference between the number of actual postings and the minimum required is due to all causes. The effects of weather and the inadequacies or non-uses of weather information are included in this difference. The difference in postings is 31,326,000 transactions times 3 less 9,526,000 or 83,500,000 postings. (There are an average of 3 postings per transaction).

[1]Cited 1, pg. 144

Based on a survey of four major ATC centers, 10% of all flight plan changes involving additional postings are made at the request of the pilot for weather reasons. This indicates that 10% of 83,500,000, or, 8,350,000 postings are attributable to weather causes. This amounts to 6% of the total number of 138,000,000 annual postings (46,074,000 transactions at 3 postings per transaction which equals 138,000,000 postings). (See Figure 23)

Another method used to calculate the percentage of all ATC delays caused by weather yields the same 10% figure. From a Study by Cook Research Laboratory[1] approximately 75% of all ATC delays during marginal weather periods are attributable to weather causes. In order to adjust these figures to an annual basis, where both good and bad weather periods are encountered, climatological studies have been made use of[2]. Based on a three year period at 21 nationally distributed airports, the study shows that critical weather conditions which affect ATC operations, occur approximately 15% of the time. Applying this factor to the ATC weather delays during marginal weather periods yields a ratio of 10%.

While the elimination of these additional postings would result in a decrease in the controller's workload, the more extensive use of weather information in arriving at decisions in the issuance of his flight clearances may add to his workload. However, the net effect appears to be a decrease in over-all workload. There will be a definite improvement in the quality of the controller's service.

- The elimination of communication caused by pilot encountered weather problems will leave the controller more time for control communications and control decisions.
- With better knowledge of the weather and

[1] "Chicago Area Air Traffic Flow and Delay Analysis", FAA/BRD-42, Sept. 1959

[2] "Quantitative Assessment of the Performance Characteristics of the Airways Terminal Forecasting System", Aerometric Research, Goleta, Calif. April 1962

its distribution and movement, especially during critical weather periods the operational efficiency of the controller is increased.

- By elimination of pilot requested flight plan changes which constitute a duplication of work, the controller will be able to handle a larger number of pilots.

While this is difficult to assess in terms of dollars it is a definite benefit to the system.

A further point here may be made of the increased confidence with which the controller makes operational decisions, based on more accurate and more timely weather information. This is directly reflected in the efficiency and smoothness of the controlled air traffic.

The Project Beacon Report indicates that the ATC operation of the future will require computer controls for proper processing of the expected traffic. From the foregoing remarks it is obvious that any computer developed for this purpose will of necessity require objective types of weather information for successful integrated operation.

b. By the Air Carriers

In order to estimate the extent of ATC delay due to weather causes experienced by the air carriers, the total delay was first determined. An air carrier sample was used as the basic source of data because, of the three types of aviation activity, the air carriers are the only group which maintains adequate records for this purpose. The basic sample employed covered the activities of one major trunk carrier for January, February and March of 1961, and all control delays associated with departures and arrivals were derived from this sample. To include a factor for enroute control delays another sample, supplied by the same carrier and covering the 12 months from July 1, 1960, thru June, 1961, was utilized. The delay contained in the latter

sample was not listed as an ATC delay but was associated with altitude clearances enroute. This delay was later added to the ATC departure and arrival delays in order to obtain a comparison between the values arrived at in this manner and the considerably larger values derived from a three carrier sample in another study[1]. This comparison will be made at the end of this section.

1) Estimated Hours of Delay

Control system delays per flight were derived from the carrier sample by obtaining delay figures from pilot log forms, applying these to the total sample activity to get a mean duration of delay in minutes based on all flights, whether delayed or not, and then applying these mean values to total air carrier activity. Table 34 shows the percent of flights delayed and delay in minutes per delayed flight for the sample. The absence of enroute values for Table 34 has been explained above.

Table 34. Percent of Flights Delayed and Minutes of ATC Delay Per Flight

Activity and Delay Cause	Turbojet[2]		Propeller	
	Percent Flights Delayed	Minutes of Delay per Delayed Flight	Percent Flights Delayed	Minutes of Delay per Delayed Flight
Departure				
Field traffic	12.4	3.65	13.7	2.9
Clearances	4.0	5.1	6.0	4.8
Enroute				
Arrival				
Clearances	15.1	7.35	15.6	6.1
Field Traffic	6.65	2.8	4.5	2.1

[1]Economic Criteria for FAA Expenditures - FAA/BRD-355, United Research, Inc.

[2]DC-8 and B-720 aircraft were included in the sample and straight averages were employed since the activity levels were nearly equal.

Table 35 shows the sample total departures and arrivals, the total number of flights delayed, and the total minutes of delay. In the last column the delay per flight is listed. This value results from dividing total flights into total minutes of delay. Enroute delays are included in this table; data were available in the form of total minutes of delay for 55,080 turbojet flights and 270,378 propeller driven flights. These enroute delays were associated with altitude changes only.

Table 35. Minutes of ATC Delay Per Flight

Aircraft	Activity	Total* Flights	Total Flights Delayed	Total Minutes of Delay	Mean Duration of Delay for Each Flight, Minutes
Turbojets	Departure	12,797			
	Clearances		516	2,727	.21
	Field Traffic		1555	5,713	.45
	Enroute			5,318	.096
	Arrival	12,742			
	Clearances		1931	14,734	1.2
	Field Traffic		793	2,179	.17
Propellers	Departure	59,279			
	Clearances		3559	17,542	.29
	Field Traffic		8135	23,535	.40
	Enroute			16,322	.06
	Arrival	59,250			
	Clearances		9260	56,229	.95
	Field Traffic		2651	5,548	.09

*Arrival and departure figures do not agree because a few reports were not completely filled out.

In Table 36 the mean duration of delay in minutes for every flight, hereafter called the delay factor, is applied to the entire air carrier fleet. The totals are seasonally adjusted by a factor of 90.7%. This factor was derived from an analysis of the seasonal variance in schedule performance[1] and was applied here since the basic departure - arrival data covers only the period January, February and March.

Table 36. Delay Factor and Total Hours of ATC Delays, 1960

Activity Cause	Aircraft Type Total Flights	Delay Factor (minutes)	Total Hours Delay	Seasonally Adjusted Total Hours
Departure	Turbojet			
Clearances	100,600	.45	754	
Field Traffic	100,600	.21	342	
Enroute	100,600	.096	166	
Arrival				
Clearances	100,600	1.20	2,012	
Field Traffic	100,600	.17	285	
Sub Total		2.13	3,559	3,228
Departure	Propeller			
Clearances	3,579,000	.29	17,298	
Field Traffic	3,579,000	.40	23,860	
Enroute	3,579,000	.06	3,579	
Arrival				
Clearances	3,579,000	.95	56,668	
Field Traffic	3,579,000	.09	5,368	
Sub Total		1.79	106,773	96,843
Weighted Delay Factor		1.80		
GRAND TOTAL Hours of Delay			110,332	100,071

[1] See Appendix D.

Computing the total delay factor for all carrier aircraft, both turbojets and propellers, results in a weighted average of 1.8 minutes of delay per flight to be applied to the air carrier fleet in 1960. As turbojet operations are forecast to increase relative to propeller flights, this factor has been adjusted upward in making projections to 1975.

The total delays in hours were projected on the basis of forecast changes in aviation activity[1]. Table 37 summarizes the projections of flight activity through 1975 for the two aircraft types used in this study.

Table 37. Air Carrier Activity Projection by Number of Flights

Aircraft Type	1960	1965	1970	1975
Propeller	3,579,000	3,574,000	3,257,000	2,972,000
Turbojet	100,000	996,000	2,083,000	3,218,000
Total	3,679,600	4,570,000	5,340,000	6,190,000

Application of the delay factor as determined from the sample and assuming no proportionality change in future years, results in the estimated projected delay hours listed in Table 38. In arriving at the decision not to change the delay factor, it was assumed that increasing air space congestion will be offset by more efficient control. The over-all delay factor, however, does increase because of the increase in turbojet activity (see Table 37). Using FAA forecast statistics[1] as a basis, the delay factor applied to the total carrier flights yields the following delay hours:

Table 38. Seasonally Adjusted Projected ATC Delay Hours for the Air Carrier Fleet

Data Samples	Delay Factor	1960	1965	1970	1975
Turbojet	2.13	3,228	32,069	66,869	103,615
Propeller	1.79	96,843	96,708	88,130	80,419
Total		100,071	128,777	154,999	184,034

[1] FAA Forecast of Air Traffic Activity, 1960-1975

2) **Economic Loss Associated with Delay Hours and Direct Operating Costs**

The previously derived[1] dollar values of weighted average cost per hour were applied to the total estimated hours of projected ATC delay from Table 38 to obtain the total penalty in dollars due to direct operating costs of the carrier fleet in the 1960-1975 period. These losses are shown in Table 39 below:

Table 39. Air Carrier Direct Operating Costs Due to ATC Delays

Item	1960	1965	1970	1975
Total Hours Delayed	100,071	128,888	154,999	184,034
Cost Per hour (see Part I, Page 20	$375	$500	$570	$578
Adjusted Cost Per hour (see Part I, Page 21	$295	$395	$448	$454
TOTAL COST, (in millions)	$29.50	$50.88	$69.44	$83.54

3) **Economic Loss Associated with Delay Hours and Lost Passenger Time**

Previously derived hourly costs of passenger time (Part I, A, 2) were applied to ATC delay hours. An average number of passengers of 71 for turbojets and 34 for propeller driven aircraft was used. Weighted numbers were determined from type utilization to arrive at the average number of passengers per hour of delay (Table 40).

[1] Tables 1 and 5

Table 40. Passenger Time Loss Associated with ATC Carrier Delays

Item	1960	1965	1970	1975
Total ATC Delay Hours	100,071	128,777	154,999	184,034
Number of Passengers Per Hour (Weighted Average)	35	43	50	55
Total Passenger Hours of Delay (millions)	3.50	5.53	7.75	10.12
Cost per passenger hour	$6.50	$7.35	$8.50	$9.40
TOTAL COST OF PASSENGER DELAY (million dollars)	$22.75	$40.65	$65.86	$95.13

c. By General Aviation

1) Estimated Hours of Delay

A rational basis for estimating general aviation ATC delays is to employ the ratios of general aviation flights to air carrier flights contacting the Air Traffic Control System.

It was assumed that general aviation aircraft contacting control centers were operating on an IFR flight plan and therefore would experience control delays proportional to those of the air carriers. This assumption appears to be valid since all contacts are described in the FAA reference[1] as being made by IFR flights.

[1] FAA Air Traffic Activity, CONUS, 1960-1975, September, 1961

The following ratios are thus established:

Table 41. Ratio of General Aviation IFR Flights to Carrier IFR Flights

Center Contacts	Air Carriers	General Aviation	Ratio: $\frac{G.A.}{A.C.}$ x 100%
Departures	2,009,623	296,040	14.7%
Overs	1,111,127	128,578	11.6%
Instrument Approaches	527,689	141,946	26.8%

With these ratios the total general aviation ATC delays can be estimated from the known carrier delay hours. The procedure followed here has been to summarize all delay hours for the calendar year 1960. Using this value, the projections to 1975 have been obtained from the factors by which general aviation IFR flight activity is forecast to increase[1].

Table 42. Total Estimated Hours of ATC Delays in General Aviation, 1960-1975

Item			1960	1965	1970	1975
Activity	Carriers Delay Hrs.	GA AC %[2]	General Aviation, Hours			
Departures	42,254	14.7	6,210			
Enroute	3,745	11.6	435			
Arrival	64,333	26.8	17,300			
Total 1960 Delays	110,332		23,845			
Seasonally Adjusted (90.7%)	100,071		21,620			
General Aviation IFR Flying Hours (Factor Based on 1960 Hours)[1]			1.0	1.6	2.5	3.67
Total Estimated Hours of Delay			21,620	34,800	54,000	79,000

[1] FAA Air Traffic Activity, CONUS 1960-1975, September, 1961
[2] See Table 41, above.

Table 43. Average 1960 Direct Operating Cost for Business and Commercial General Aviation IFR Aircraft

Aircraft Class	Hours Flown in thousands	% of Total	Cost/Hour Dollars	Proportional Cost-Dollars
Single Engine 4 place				
up to 200 h. p.	2,904	36	20.00	7.20
over 200 h. p.	2,867	36	30.00	10.80
Multi-Engine				
up to 800 h. p.	1,272	16	65.00	10.40
800-2000 h. p.	457	6	80.00	4.80
over 2000 h. p.	460	6	130.00	7.80
Average cost/hour				41.00

With these hourly operating costs the total direct operating losses have been computed and are presented in Table 44.

Table 44. General Aviation Total Direct Operating Costs Associated with ATC Delays

Item	1960	1965	1970	1975
Total ATC Delay Hours	23,300	37,500	57,900	81,000
Operating Cost/Hr. (Average IFR Aircraft)	$41.00	$41.00	$41.00	$41.00
Total Operating Losses (millions)	$0.95	$1.44	$2.37	$3.32

2) Economic Loss Associated with Delay Hours and Direct Operating Costs

In order to assess the economic loss from direct operating costs involved in ATC delays, the direct operating costs for IFR general aviation have been derived from statistics on percentage usage by aircraft class[1]

[1] FAA Statistical Handbook, 1961 Edition

and estimates of the types of aircraft utilized for general aviation business and commercial use and of the costs of operating these aircraft. The estimated costs include fuel, oil, maintenance, insurance and depreciation based on a 250-300 hour utilization per year. Crew cost is included for multi-engine aircraft over 800 horsepower, Table 43 lists the various factors and the average operating cost.

3) Economic Loss Associated with Delay Hours and Lost Passenger Time

As in the case of the carriers, passenger time is lost when general aviation aircraft, flying on business, are delayed. The passengers who utilize general aviation business and "for hire" aircraft and are associated with IFR flights are assumed to be executives and salesmen whose earnings are an average of $20,000 per year. Based on 2000 work hours per year, their time is worth approximately $10.00 per hour. From Federal Aviation Agency statistics it was established that the average number of passengers per aircraft in 1960 was 3.3. The Agency forecasts 3.9 per aircraft in 1965, 4.2 in 1970 and 4.8 in 1975.

If an annual salary growth rate of 2 1/2% is assumed, the time of the passengers being discussed will be worth:

$10.00 in 1960
$11.25 in 1965
$12.65 in 1970
$14.25 in 1975

Table 45 presents the projections to 1975.

Table 45. Loss of Passenger Time

Item	1960	1965	1970	1975
Total ATC Delay Hours	21,620	34,800	54,000	79,000
Number of Passengers	3.3	3.9	4.2	4.8
Number of Passenger Hours	72,000	136,000	227,000	380,000
Cost per passenger hour	$10.00	$11.25	$12.65	$14.25
Estimated Loss of passenger time (millions)	$0.72	$1.53	$2.87	$5.40

d. **By Military Aviation**

1) **Estimated Hours of Delay**

As in the case of general aviation, the delays in military aviation were based on the ratio of total IFR operations of the Air Carriers to total IFR operations of the military[1]. The resultant factors were then applied to the known carrier delays in order to estimate the military delays. The factors are shown in the table below for FY 1961.

Table 46. Ratio, Military/Air Carrier IFR Operations

Center Contacts	Air Carrier	Military	Factor $\frac{MIL}{AC}$
Departures	2,009,623	1,050,063	52.4%
Overs	1,111,127	1,403,740	126%
Instrument Approach	527,689	246,155	46.6%

[1] FAA Air Traffic Activity in CONUS, 1960-1975

In determining the total delay due to ATC causes, incurred by military aircraft, the field traffic values were not employed because activities on military bases are not considered as within the Air Traffic Control System. Therefore, the field traffic portion was taken out of the carrier delays and the remaining total delay hours were used, to be applied to the military factors.

Table 47. Air Carrier ATC Delay Hours (Without Field Traffic)

ATC Activity and Delay Cause	Turbojet Delay Hours	Propeller Delay Hours	Total Jet and Propeller
Departure Clearances	754	17,298	18,052
Enroute	166	3,579	3,745
Arrival Clearances	2,012	56,668	58,680
TOTAL DELAYS	2,932	77,545	80,477

The preceding table now permits the application of the military delay factors to the departure and arrival delays of the carriers for the Fiscal Year 1961.

Table 48. Hours of Military ATC Delay, FY 1961

ATC Activity	Air Carrier Delay Hours	Factor $\frac{MIL}{AC}$	Total Military Delay Hours
Departures	18,052	52.4%	8,900
Enroute	3,745	126.0%	4,700
Arrivals	58,680	46.6%	27,200
Total Delay Hrs.			40,800

Using the FAA forecasts for military flying activity[1] and assuming the delays to vary by the same factor by which total flight activity varies, the projected total hours of delay in military aviation have been estimated.

Table 49. Projected Hours of Military Delay

Item	1960	1965	1970	1975
Total Delay Hours	40,800	36,300	33,200	28,100

2) Economic Loss Associated with Delay Hours and Direct Operating Costs

Due to the absence of any data on the costs involved in flying the various types of military aircraft, direct operating costs of military aircraft have been derived from air carrier values. As previously treated in Part I, A, the direct operating costs of carriers have been broken down into the various items showing Table 50.

Table 50. Factors Comprising Direct Operating Costs

Item	Percent Total Direct Operating Costs	Hourly Cost of Delays	
		Percent Used	Resultant Value
Crew Salary	8.8%	100	8.8%
Insurance	15.6%	100	15.6%
Fuel	23.5%	100	23.5%
Direct Maintenance	19.0%	100	19.2%
Indirect Maintenance	10.0%	0	0
Depreciation	22.9%	50	11.5%
TOTALS	100.0%		78.6%

[1] Forecasts of Annual Flight Activity, CONUS, 1960-75, FAA Traffic Analysis BR.

If the 78.6% figure is applied to total operating costs of air carrier delay hours, the projected hourly direct operating costs for both turbojets and propellers can be determined for the 1960-1975 period as shown on the following table:

Table 51. Hourly Operating Costs

Item		1960	1965	1970	1975
Turbojets	Total Hourly Operating Cost	$960	$880	$800	$720
	Cost Per Hour of Delayed Flight (78.6%)	$755	$692	$629	$566
Propeller Aircraft	Total Hourly Operating Cost	$320	$315	$310	$305
	Cost Per Hour of Delayed Flight (78.6%)	$252	$248	$244	$240

In the operation of military aircraft, it may be argued that crew costs should be ignored since the personnel are available in any case. Insurance costs are non-existent for the military. On the other hand, depreciation on military aircraft is more rapid and original cost is greater. Maintenance is an unknown factor but probably is more costly in military operations than for carriers. It is estimated that the elimination of crew and insurance costs is offset by the greater depreciation and probably greater cost of maintenance.

In Table 52 the hourly costs of military turbojet and propeller aircraft are estimated and projected to the 1975 period[1].

[1] Forecasts of Air Traffic Activity, CONUS, 1960-75, FAA

Table 52. Hourly Direct Operating Costs of Military Aircraft

Item		1960	1965	1970	1975
Percentage of Flying Hours	Turbojet	51.5%	59%	63%	66%
	Propeller	48.5%	41%	37%	34%
Cost Per Hour of Delay	Turbojet	$755	$692	$629	$566
	Propeller	$252	$248	$244	$240
Weighted Average Cost Per Delay Hour		$509	$516	$486	$454

Applying these hourly costs to total delay hours, estimates of the total direct operating losses due to the ATC delays in military aviation have been made and are presented in Table 53.

Table 53. Military Aviation Direct Operating Costs Due to Air Traffic Control Delays

Item	1960	1965	1970	1975
Total Hours of Delay	37,700	33,600	30,700	26,000
Cost Per Hour of Delay	$509	$516	$486	$454
TOTAL COST OF DELAYS (millions)	$19.19	$17.34	$14.92	$11.80

e. Summary of Total Losses

All the above ATC delays were based on a well documented sampling from a large integrated trunk carrier with operations extending over the entire U.S. Thus, the values found for the annual delay hours are considered fairly representative of all nationwide carrier operations. However, as a check on the correctness of this assumption an analysis was made by comparing the operations of the sample carrier at 48 airports serviced by this carrier with all U.S. carrier operations at these same airports. The major assumption made here is that traffic activity is directly related to ATC delays.

The analysis, which is treated in detail in Appendix E, estimates that total activity of all U.S. carriers is greater by a factor of 7.4% than the activity of the sampled carrier, when adjusted to total national traffic. Thus, by increasing the sum of all ATC delays computed in this section by a factor of 7.4%, the estimates are believed to approach more nearly the actual national traffic density.

The table below summarizes all ATC delay penalties and includes the representativeness factor of 7.4%. (See Figure 24)

Table 54. Summary of Penalties Due to All ATC Delays

Item	1960	1965	1970	1975
A. Air Carriers				
Direct operating costs (millions)	$29.50	$50.88	$69.44	$83.54
Lost passenger time (millions)	$22.75	$40.65	$65.86	$95.13
B. General Aviation				
Direct operating costs (millions)	$0.95	$1.44	$2.37	$3.32
Lost passenger time (millions)	$0.72	$1.53	$2.87	$5.40
C. Military Aviation				
Direct operating costs	$19.19	$17.34	$14.92	$11.80
Total Penalties (millions)	73.11	111.84	155.46	199.19
Adjusted to National Carrier Activity (factor of representativeness 1.074)	$78.52	$120.12	$166.96	$213.93

The above values represent the results of statistics considered to be the best available at the present time. However, a recent study prepared for the FAA by United Research, Inc.[1] arrives at higher estimates for the total

[1] "Economic Criteria for Federal Aviation Agency, Expenditures", June 1962 (Contract No. FAA/BRD-355)

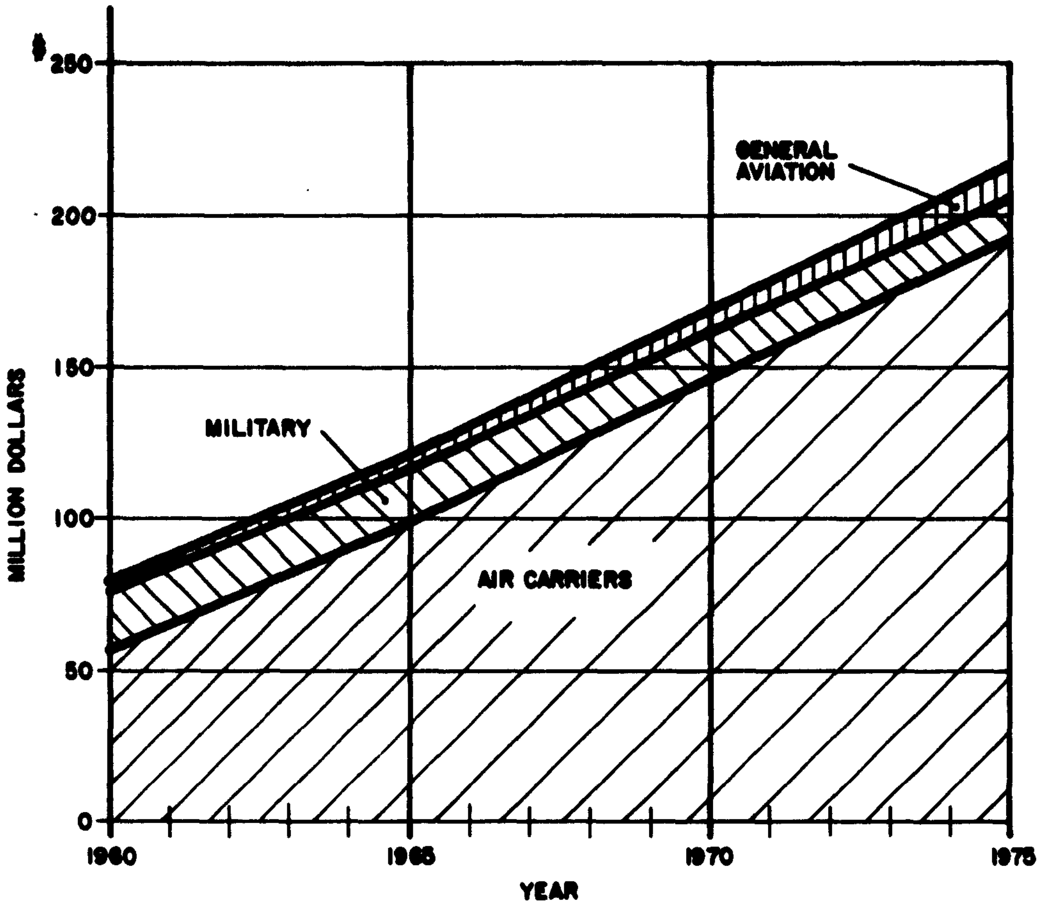

FIGURE 24. SUMMARY OF TOTAL LOSSES DUE TO ATC DELAYS

ATC carrier delays. The sampling for this study was derived from three major trunk carriers, one of which concentrates its operations almost exclusively in the high activity regions of the Eastern U.S. Thus, it is conceivable that this sample is somewhat heavily weighted towards high activity airports where the ATC delays are more numerous than the national average. Since both samples are estimates, representing a lower value and an upper value of ATC carrier delays, we will use both values here as a region of ATC penalties and apply the subsequent benefit analysis to these upper and lower limits rather than to a discrete value of annual ATC penalties. The following table lists the total penalties based on the delay hours of the United Research, Inc. report. These penalties have been plotted in the graph, Figure 25.

Table 55. Total Projected ATC Penalties Based on United Research Report

Item	1960	1965	1970	1975
Total Hours of Carrier ATC Delay, United Research Report	160,194	198,959	232,290	259,265
Total Hours of Carrier ATC Delay, This Report	100,071	128,777	154,777	184,034
Total Hours of Carrier ATC Delay Adjusted for Representativeness (factor = 1.074)	107,500	138,300	166,200	197,700
Factor of increase $\frac{\text{URI Delays}}{\text{EBA Adj. Delays}}$	1.49	1.44	1.40	1.30
Total Penalties Based on URI Delays (millions)	$110.00	$164.0	$218.0	$260.0

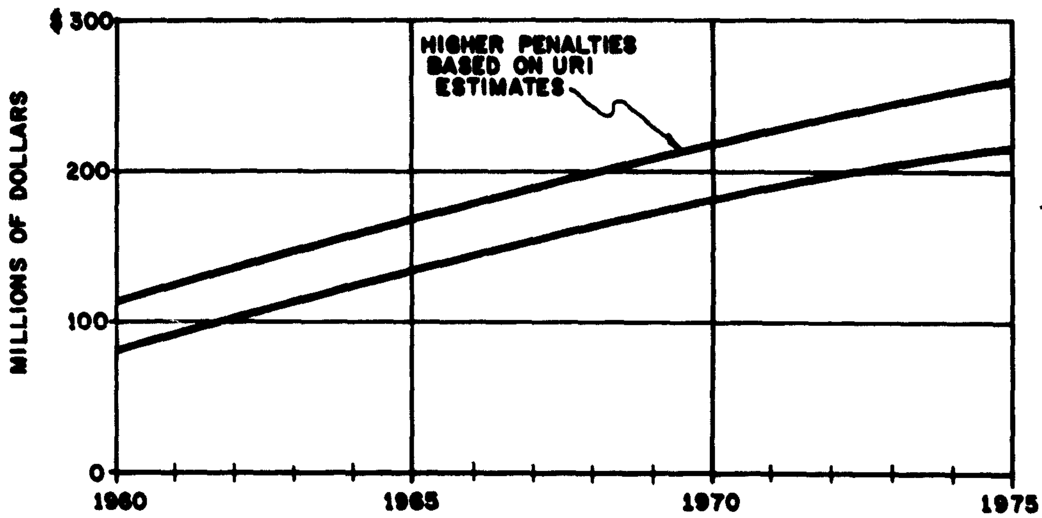

FIGURE 25. TOTAL PROJECTED PENALTIES DUE TO ATC DELAYS (in million dollars)

4. Penalties from ATC Delays Due to Weather Causes

In Part I. C. 3. e., the total delays experienced by aircraft in the air due to all traffic control causes and the associated economic penalties have been summarized. A portion of these delays is independent of weather and is caused primarily by traffic congestion due to scheduling. The remaining portion is due to weather causes. A number of studies have been made to single out the various causal factors of ATC delays. A case study performed by Cook Research Laboratories[1] analyzed the total number of ATC delays and delay time during typical VFR weather days and during marginal weather periods.

Approximately 75% of all ATC delays which occurred during the periods of bad (or marginal) terminal weather in this study were attributed to the weather. To assess the reduction of this delay which could be accomplished by communicating better and more timely weather information to the ATC system, it was necessary to determine the total effect of the weather itself, segregate the phenomena associated with delay, and then attempt to evaluate the results of improving the information conveyed about these phenomena.

Climatologically, marginal weather has been estimated to exist over the United States 18.5% of the time[2]. Application of this climatological value to the 75% value results in a percentage of 13.9 which represents the weather contribution to the total delay of the ATC system. For the purposes of this analysis a figure of 10% will be used. The following table lists the projected dollar losses from ATC delays due to all weather causes:

---

[1] Chicago Area Air Traffic Flow and Delay Analysis, Summary Report, Volume I, September 15, 1959

[2] "Quantitative Assessment of the Performance Characteristics of the Airways Terminal Forecasting System", Aerometric Research, Inc. Contract Cwb 10077, USWB

Table 56. Summary of Penalties From ATC Delays Due to Weather Causes (in million dollars)

Item	1960	1965	1970	1975
Total Penalties due to ATC Delays				
Lower value	$78.52	$120.12	$166.96	$213.93
Upper value	110.00	164.00	218.00	260.00
Penalties from ATC Delays Due to Weather Causes (10% of Total)				
Lower value	7.85	12.01	16.70	21.39
Upper value	11.00	16.40	21.80	26.00

PART II

COST ANALYSIS OF PRESENT AVIATION WEATHER SERVICES

PART II

COST ANALYSIS OF PRESENT AVIATION WEATHER SERVICES

A. INTRODUCTION

B. DESCRIPTION

C. ESTIMATED COST TO THE PARTICIPATING AGENCIES

D. SUMMARY OF TOTAL COSTS

ESTIMATED COST OF THE PRESENT AVIATION WEATHER SERVICE

A. INTRODUCTION

The aviation weather service exists for the purpose of providing timely weather information in a format that is useful and intelligible to airspace users and air traffic controller / managers to assist them in making decisions in the conduct of their operations. To provide this information, meteorological phenomena are observed and measured, these observations are processed into analyses and forecasts of future conditions, and this information is then presented to the operational users. Communication links of various kinds are used to transport the information between the various parts of the service and to the ultimate users.

The present aviation weather service is supported primarily by the combined and coordinated efforts of two government agencies: the U.S. Weather Bureau and the Federal Aviation Agency. The Navy and Air Force also make appreciable contributions to the service, principally in the field of weather observations, taken in support of their own operations, which are made available to the civil system. In arriving at an estimate of the cost of the aviation weather service, it will be advantageous to first present a brief description of the service and how it operates.

B. DESCRIPTION

The aviation weather service is most conveniently described as a system comprised of four principal components or subsystems, as follows:

<u>Observing</u> -- This subsystem senses the meteorological parameters with instruments or the human eye and provides processing of some parameters automatically. The observing subsystem includes not only the configurations, layout and exposure of the sensing elements themselves, but also the auxiliary equipment necessary for preliminary processing at the observing site and the procedures used in converting raw signals into meteorological information.

Processing -- This subsystem receives meteorological data transmitted from the observing subsystem and alters it in preparing information for transmission to the presenting subsystem. Processing may include smoothing, screening, summarizing, and analyzing observations as well as preparing forecasts. Some measurements are smoothed, averaged, and converted at the observing site and transmitted directly to the presentation subsystem.

Presenting -- This subsystem links the aviation weather system with the operational users by providing the weather system products. Usually these products are presented in their original form as received; occasionally they are modified by combination, integration, and interpretation into a "presentation product" which can be easily assimilated by the user.

Communicating -- This subsystem transports information from one geographical location to another between the other subsystems. Whatever informational errors are introduced into the system will be transported without correction, since communicating links do not affect message content. In practice, an operational communication system adds errors of its own because of noise and an occasional malfunction.

The relationships between the four subsystems and their contributions to the total system are shown in Figure 26. As in all complex systems, the over-all performance of the aviation weather system can be no better than that of its component parts. The most sophisticated processing techniques cannot improve on information obtained from the observing subsystem; a perfect forecast that is garbled in the communicating subsystem or offered in unintelligible form by the presenting subsystem will be of no assistance to the ultimate user and thus fail in its purpose.

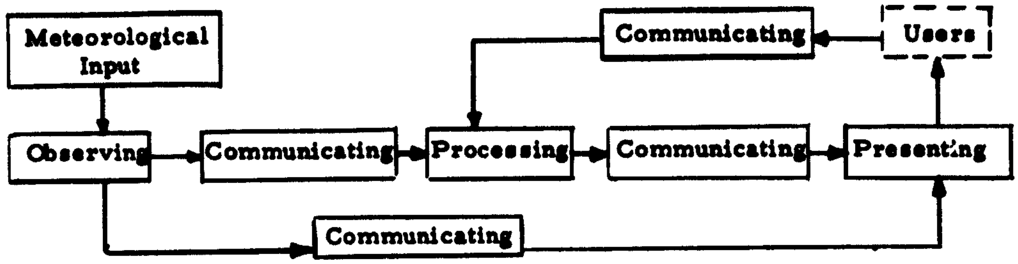

Figure 26. Primary Elements of the Aviation Weather System

1. Observing Subsystem

The initial source of information for the entire aviation weather system is the observing subsystem. It observes and records the weather conditions and parameters that are processed into the analyses and forecasts that are used in aviation operations. All observations are transmitted by the communicating subsystem to the processing subsystem; some are also transmitted directly to the presenting subsystem for immediate use. The observations made are customarily divided into four categories:

Surface observations
Upper air observations
Radar weather observations
Enroute observations (pilot reports)

In addition to the above, numerous observations of use to aviation meteorology, but not obtained primarily for aviation operations, are available to the system; for example, observations from ships at sea and from foreign countries.

a. Surface Observations

Surface observations are made from the ground by human observers and by means of instruments. They include such parameters as surface wind speed and direction, surface visibility, cloud base and amount,

surface temperature and dew point, atmospheric pressure, precipitation, and thunderstorms. Stations in the surface observing network are operated by a number of agencies and organisations: the U. S. Weather Bureau, the Federal Aviation Agency, airline and airport personnel and the military.

Surface observations are obtained from:

199	Weather Bureau Airport Stations
21	Automatic Meteorological Stations
198	Federal Aviation Agency Stations
14	Joint Weather Bureau - Federal Aviation Agency Stations
133	Supplementary Aviation Weather Reporting Stations
9	Joint Weather Bureau-Supplementary Stations
36	Stations with part-time Weather Bureau employees
45	Navy and Marine Corps Air Stations
110	Air Force Bases
10	Weather Bureau Stations not at airports
675	Total

In addition to the above, personnel certified by the Weather Bureau take observations at a number of airports to legalize landings and take-offs of commercial carriers; these observations are for local use only and are not transmitted.

Observations are made hourly, 24 hours a day, at a majority of the stations. The supplementary and part time stations take observations only during hours of commercial carrier operations. Observations are also taken whenever an operationally significant change in weather occurs.

b. Upper Air Observations

Observations by radio of wind direction and speed, pressure, temperature, and humidity at various altitudes are taken every twelve hours at 65 installations operated by the Weather Bureau. Two Air Force bases also take similar observations on the same schedule. The average maximum altitude attained by these observations is around 60, 000 feet.

At the intermediate six-hour intervals, some of these stations make radio wind or pilot balloon observations. At 79 other locations pilot balloon measurements of upper wind direction and speed are made one or more times a day.

c. Radar Weather Observations

Observations by radar of the size, intensity, development, and speed and direction of movement of precipitation areas are made at a number of observation sites, principally in the eastern two thirds of the U.S. These are collected over special teletype circuits (RAWARC) at Kansas City and an hourly summary disseminated over Service A.

The Weather Bureau operates 24 long range and 67 medium range radars and also receives reports from 11 cooperative radar weather sites. Most military air bases have weather radar used principally for local storm warnings. In addition the Air Force operates a network of 26 long range weather radars furnishing synoptic weather radar information which is relayed to the Weather Bureau.

d. Enroute Observations

Observations of the weather in the areas between the ground observing sites are obtained from pilot reports, as well as weather radar. Pilots flying through these areas are able to observe and report the location and altitude of cloud bases, tops, layers; wind speed and direction at flight altitude; free air temperature; location, type and intensity of icing and turbulence; location, orientation, direction of movement of individual weather systems such as line squalls.

2. Processing Subsystem

The processing subsystem receives the various observations and from them produces analyses of present conditions and forecasts of future conditions. Some of these products are presented to operational users and some are used within the processing subsystem itself. The processing subsystem operates in a series of steps. In general, in each succeeding step the geographical coverage of the product decreases, the detail increases, and the period of validity shortens.

a. National Meteorological Center

The National Meteorological Center is located at Suitland, Md. Here observations of all kinds are received from the entire Northern Hemisphere and processed into large scale analyses and forecasts, some 140 products in all. These products are designed for all categories of meteorology, not aviation alone, and consequently the terminology and units used are meteorological.

b. Guidance Forecast Centers

The next step in the processing subsystem is performed at the eight guidance forecast centers. Using the basic analyses and forecasts received from the National Center, plus additional observations plotted locally, forecasts covering smaller areas are produced which are designed to assist meteorologists in producing operational forecasts.

c. Flight Advisory Weather Service Forecast Centers

The bulk of the processing is carried out at the twenty-five Flight Advisory Weather Service Forecast Centers (FAWS). The United States is divided into twenty-five areas for this purpose and a FAWS forecast center is assigned forecast responsibility for each. The following forecasts are prepared every six hours, amended as necessary:

Twelve hour terminal forecasts (FT-1) are prepared for a total of 350 terminals. The weather items included are heights and amount of sky cover, visibility, weather and obstructions to vision, surface wind direction and speed (if more than 10 knots) and remarks.

Twenty-four hour terminal forecasts (FT-2) are prepared for a total of 113 terminals. The weather elements are the same as for the twelve hour forecasts.

Area Forecasts (FA) are prepared by each center for their respective areas of responsibility. They contain a twelve hour forecast of amount and height of sky cover, location and movement of weather-producing fronts, surface visibility, state of weather and obstructions to vision, surface winds, areas of icing and turbulence. They also include weather outlook for the succeeding twelve hour period.

Upper Wind Analyses (AW) are prepared for 142 locations. These are twelve hour forecasts of wind direction and speed at certain specified levels. Some of the forecasts include temperature.

Regional Synopses (FN) are prepared at five FAWS forecast centers. These are twenty-four hour forecasts of the location, expected movement and development of major weather features, and areas of significant weather.

In-flight Weather Advisories (FL) are prepared at each FAWS forecast center in order to give airmen in flight advance notice of impending weather developments or trends that are potentially hazardous. There are two categories, the "Sigmet" advisory for conditions that are hazardous to all aircraft,

and the "Advisories for small aircraft" for conditions that are hazardous to light aircraft (less than 12,500 lbs.)

d. Weather Bureau Airport Stations

The final steps in the processing system are performed at the Weather Bureau Airport Stations. These stations may make short period changes in the forecast for their terminal (as received from the responsible FAWS forecast center) if local weather conditions indicate it to be necessary.

e. Other Processing Centers

Forecasts of the occurrence of tornadoes and severe thunderstorms are prepared by the Severe Local Storm Warning Center at Kansas City, Mo. The Hurricane Warning Center, Miami, Fla., has the responsibility of preparing forecasts for hurricanes and tropical storms for the Atlantic and Gulf Coasts. The Hurricane Warning Center, San Francisco, Calif., has a similar responsibility for the Pacific Coast.

The military services maintain forecast centers which prepare forecast products in support of their respective operations. These products are not available to civilian aviation.

Terminal and area forecasts for Canadian airports are prepared by the Canadian Meteorological Service and relayed to the U.S. via Service A teletype circuits.

3. Presenting Subsystem

Meteorological information is delivered to the ultimate user by means of the presenting subsystem. There are two categories of operational users: aviation operations and the air traffic control system. Information is presented in two modes: visual and aural. Visual material consists of: (a) printed sequences of weather observations, forecasts and advisories and pilot report and

radar summaries, received via teletype, (b) handwritten copy of local observations received via tel-autograph (c) chart portrayals of weather analyses, summaries and fixed time forecasts received via facsimile.

Aural material consists of terminal observations, terminal and area forecasts, pilot report summaries, in-flight advisories delivered via (a) continuous or scheduled broadcasts delivered over FAA radio facilities (b) automatic telephone transcriptions (c) personal telephone conversations and (d) person-to-person briefings, usually in conjunction with visual materials.

a. Presentation to Aviation Operations

Weather information is presented to aviation personnel at four types of locations:

Flight Service Stations (340) and Combined Station/Towers (72)
Weather Bureau Stations (260) and Military Air Bases (190)
Ground Remote Areas
In Aircraft

The numbers given above are reasonably accurate but may be slightly different at any given time due to decommissioning and commissioning of stations.

(1) <u>Flight Service Stations</u>

Personal briefings at Flight Service Stations are usually aural assisted by the weather information received over the Service A teletype circuit. This consists of:

Terminal weather observations from the local circuit plus selected observations from other circuits.

Individual pilot reports and pilot report summaries.

Radar weather summaries.

12 hour terminal weather forecasts for selected terminals to a distance of several hundred miles.

12 hour area forecasts for the local and several adjacent areas, plus an outlook for the succeeding twelve hours.

In-flight advisories when in effect.

Forecast of hurricanes and severe local storms when occurring.

Other visual information available consists of direct reading dials of altimeter setting and wind speed and direction.

In telephone briefings, the Flight Service Station personnel will read from the Service A material those pieces of information requested by the pilot, as well as any other material considered pertinent to the particular flight in question.

The Federal Aviation Agency maintains direct, no expense telephones from 66 airports with no weather briefing facilities to the nearest Flight Service Station for the purpose of filing flight plans and obtaining weather information. The Agency also maintains 50 "Foreign Exchange" telephones, whereby a pilot may dial a number in his own city and be connected with the nearest Flight Service Station for the same purpose. Pilots in the air may also receive weather information by radio on request from Flight Service Stations.

The Combined Station/Towers are able to furnish pilots only the local weather conditions at their particular terminal via telephone or radio.

(2) Weather Bureau Stations and Military Air Bases

Weather Bureau Stations as well as Navy and Marine Corps Air Stations receive the same Service A material as the Flight Service Stations. They also receive information over the Service C teletype (which is primarily non-operational in character) and in some cases overseas and

foreign weather information on the Service O teletype. The aviation weather information which they receive, which is not available to flight service stations, consists of:

24 hour terminal forecasts for a limited selection of terminals.

One or more of the five regional synopses, which are specifically designed for the enroute portion of long haul transport flights.

Air Force Bases receive similar information via the Air Force operational teletype circuit, which is similar to Service A, and the Air Force Synoptic teletype circuit, which is similar to Service C and O.

In addition to the above printed material, all military and most Weather Bureau stations receive graphic material via facsimile. The charts consist of summaries, analyses and fixed time forecast of various meteorological parameters. These charts are designed for use by meteorologists and the material on them requires considerable interpretation by a meteorologist before it can be applied to aviation operations.

Presentation at these stations is similar to that at Flight Service Stations except that, in addition to having graphic material to assist, the briefing is usually done by a trained meteorologist who is qualified to interpret and elaborate on the basic information received from the processing subsystem.

No-expense and foreign exchange type telephone service is not provided into Weather Bureau Stations. However, at some 30 of them, a 12 hour forecast of significant weather conditions within a 250 mile radius is routinely prepared and put on tape. By dialing the unlisted number of the station (unlisted in order to avoid swamping the system with calls from the non-flying public) the forecast is played back by an automatic answering device.

Experimental closed-loop television is installed at the Weather Bureau Stations at Idlewild, N. Y., and Miami, Fla., between the forecast office and the pilot's pre-flight area. This system provides a person-to-person, combined visual and aural briefing without the necessity of the pilot visiting the weather office.

(3) Ground Remote Areas

Ground remote areas are defined as those locations where pilots do not have physical access to a weather briefing facility, such as small airports, the pilot's home or office, etc. All presentation is by means of radio or telephone.

Telephone briefings may be obtained from the nearest Flight Service Station or Weather Bureau Airport Station. In the event that neither the no-expense interphone, foreign exchange telephone nor automatic telephone weather answering service is available, regular telephone channels must be used, usually necessitating a toll call.

A continuous transcribed aviation weather broadcast is currently being prepared by Weather Bureau units and broadcast from 56 FAA low-medium frequency navigational facilities. The content is the same as the automatic telephone weather forecast with the addition of significant pilot reports, in-flight advisories and the local and nearby terminal weather observations.

Scheduled weather broadcasts are made from all airway communication stations having voice facilities, over continuously operated radio ranges or radio beacons. At 15 minutes past each hour, an area type broadcast is made, consisting of terminal weather observations from selected terminals within 150 miles. At 45 minutes past the hour a route type broadcast is made consisting of weather observations from selected terminals along airways within 400 miles. Effective in-flight advisories are included in both broadcasts.

(4) Pilots in Aircraft

Presentation of weather information to pilots in aircraft is accomplished by means of radio, either two-way voice or broadcast. Five methods are commonly employed and a sixth is being tried out experimentally at two locations. The methods are:

Flight Service Station Radio is available to aircraft having standard two-way radio equipment. Weather briefings are similar to those obtained by telephone. The pilot may use either the navigational aid frequency or a voice communication frequency.

Air Route Traffic Control Center Radio is also available to aircraft having standard two-way radio equipment. Weather information is transmitted from centers only when the controller workload permits and is limited in scope. Since the transmission of weather information is only a secondary responsibility of centers, requests for weather information are not encouraged.

Control Tower Radio is available to aircraft with standard two-way radio equipment. Only local terminal weather conditions are available from towers.

Continuous Transcribed Weather Broadcasts are available to aircraft having L/MF receivers. These are the same broadcasts described under ground remote areas.

Scheduled Weather Broadcasts are available to aircraft having the necessary receiver. They were also described under ground remote areas.

Pilot-to-Forecaster Service provides a direct link via radio on 122.6 mc between airborne pilots and weather forecaster personnel. This is an experimental service currently in operation

only at Kansas City, Mo., and Washington, D.C. The military weather services provide a similar service from about 100 locations in the U.S., using UHF Channel 13. Some commercial carriers provide this service to their pilots employing company frequencies.

b. Presentation to the Air Traffic Control System

Weather information is presented to the personnel of the air traffic control system at four types of locations:

Airport Traffic Control Towers
Air Route Traffic Control Centers
Radar Approach Control Centers
Flight Service Stations, already discussed above

(1) Airport Traffic Control Towers

Towers receive the local terminal weather observation in handwritten copy via tel-autograph from the local weather observing activity. They also receive wind speed and direction and altimeter setting via direct-reading dials. Some towers are provided with direct readouts of ceiling, temperature and runway visual range. If a Weather Bureau Airport Station is in the vicinity, a comprehensive weather briefing may be obtained, either in person or by telephone.

(2) Air Route Traffic Control Centers

Most centers have a drop on the Service A teletype and receive the same weather information as was described under Flight Service Stations, i.e., terminal observations and forecasts, area forecasts, upper wind and temperature forecasts, in-flight advisories, etc. This material is usually posted in the vicinity of the watch supervisor's position.

All center controller positions are equipped with either direct telephone lines or intercom connections to Weather Bureau Offices, for the purpose of receiving weather briefings or relaying pilot reports.

(3) Radar Approach Control Centers

These centers receive weather information of the same type and via the same methods as the air route traffic control centers.

4. Communicating Subsystem

The communicating subsystem transports weather information between the observing, processing and presenting subsystems to the operational users. Five standard methods are used:

- Teletypewriter
- Facsimile
- Radio
- Telephone
- Television

a. Teletypewriter

The primary means of collecting and disseminating weather information is by teletypewriter circuits, which provide an economical means of handling a large bulk of information. Teletype circuits are maintained by the FAA, the Weather Bureau and the Air Force.

The circuits operated by the FAA are:

Service A for the collection and distribution of observations and forecasts to operational users. It consists of 15 area circuits, 14 supplementary circuits, and a variable number of local circuits. The area circuits meet the requirements of the majority of users. The supplementary circuits provide additional information to satisfy the needs of particular users. The local circuits are used to furnish individual FAWS forecast centers additional information, not available on the area and supplementary circuits at their particular location. High speed (1000 wpm) equipment is used to transfer information from area to area for inter-area distribution. The low speed (100 wpm) is used for area collection and dissemination of information. There are about 2400 drops of all kinds on Service A.

Service B which is the FAA operational circuit whose primary purpose is for air traffic control. However, it is used for the collection of pilot reports and their delivery to the FAWS forecast centers and thus serves the aviation weather system also.

Service C for the collection and distribution of meteorological observations, analyses and forecasts to meteorological users. It consists of six area circuits, operating at a speed of 100 wpm. There are approximately 450 drops on Service C.

Service O for the collection and distribution of overseas observations and forecasts to operational and meteorological users. It is composed of five circuits, operating at a speed of 100 wpm. There are approximately 90 drops on Service O.

The circuits operated by the Weather Bureau are:

Radar Warning Circuit (RAWARC) for the exchange of radar weather reports and the distribution of severe local storm and tornado warnings. It consists of three circuits with a total of 146 drops, each circuit terminating at Kansas City.

Hurricane Warning Circuits for the collection of special weather reports and the distribution of hurricane and tropical storm warnings and advisories. This circuit is in operation only during the Atlantic and Gulf Coast hurricane season.

Local Circuits for the exchange of special weather information between Weather Bureau, FAA, airlines, local officials, utilities, etc., in metropolitan areas.

The circuits operated by the Air Force are:

USAF Operational Weather Teletype Network which is similar to Service A.

USAF Synoptic Weather Teletype Network which is similar to Service C.

Inter-area Weather Teletype Circuits

Air Defense Command Division Weather Networks

b. Facsimile

Facsimile circuits, operated by the Weather Bureau and Air Force, are used to disseminate weather information in graphical form to users and exchange such information between forecast centers. The information consists of analyses, summaries and fixed time forecasts in chart form.

The circuits operated by the Weather Bureau are:

The National Weather Facsimile Circuit transmits primarily from the National Meteorological Center at Suitland, Md. Over 100 maps per day are transmitted at the rate of about 10 minutes per map, depending upon the size. The circuit operates at the rate of 120 scans per minute. There are approximately 200 drops in Weather Bureau offices, 300 in military offices and 150 in private offices.

The High Altitude Facsimile Circuit exists primarily for the purpose of exchanging high altitude (above 25,000 feet) weather information between the seven Weather Bureau High Altitude Forecast Centers. It operates at a rate of 120 scans per minute and has about 40 drops.

The Air Force operates several facsimile circuits in the continental United States for the purpose of disseminating information in support of Air Force operations.

c. Radio

Radio frequency links are used primarily for the communicating of meteorological information to airborne pilots by ground stations. Two methods are used, each for a specific purpose; they are:

Broadcast - for the provision of routine weather information to all airborne pilots within receiving range. Only a receiver is required in the aircraft for this purpose.

Air-ground - for the non-routine provision of weather information to a particular airborne pilot. This requires standard two-way radio in the aircraft.

Broadcasts are of two types, continuous and scheduled.

a. A continuous transcribed aviation weather broadcast is currently being issued from 56 FAA low-medium frequency air navigational facilities. A total of 87 such broadcasts is planned which will cover almost the entire U.S.

b. Scheduled weather broadcasts are made from all airway communication stations having voice facilities, over continuously operated radio ranges or radio beacons. They are made at 15 and 45 minutes past each hour.

Air-ground communication with airborne pilots is accomplished through the following ground facilities:

a. Flight Service Station Radio
b. Air Route Traffic Control Center Radio
c. Airport Traffic Control Tower Radio
d. Pilot-to-forecaster Service (two experimental units at present)

d. Telephone

Telephone links are used routinely in the aviation weather service only for the purpose of pilot briefing by Weather Bureau or Flight Service Station personnel. However, extensive use of telephone links is made for the non-routine exchange of information between weather service personnel, operations personnel, air traffic control personnel and others.

In addition to the normal telephone channels, a number of special facilities are provided. The FAA maintains no-expense interphone from 66 outlying airports to the nearest Flight Service Station, and foreign exchange telephone service in 50 communities without weather service. The Weather Bureau provides automatic telephone weather answering service at about 30 locations. Local, around-the-field, interphone is available at many locations.

e. Television

Closed circuit television between the weather office and the pilot pre-flight areas is widely used at military air bases for pilot briefing purposes. This system permits a person-to-person briefing, using visual materials as an aid. The Weather Bureau has installed this system at Idlewild, N.Y., and Miami, Fla., on an experimental basis.

5. <u>Research and Development</u>

Both agencies, the Weather Bureau and Federal Aviation Agency, support research and development programs aimed at improving various parts of the aviation weather service as well as the service as a whole. In addition, the military, the National Science Foundation and the National Aeronautics and Space Administration support broad research programs, the results of which may ultimately be of benefit to the aviation weather service.

6. Administrative Direction and Support

In addition to the operating personnel, maintenance personnel and equipment, the Weather Bureau and the Federal Aviation Agency provide administrative direction and support for the various subsystems and the aviation weather service as a whole.

C. ESTIMATED COSTS TO THE PARTICIPATING AGENCIES

The 1962 fiscal year budget figures have been used as the basis for estimating the costs of the aviation weather service to the participating agencies. These figures have been rearranged under the sub-headings of the preceding section, i.e., observing, subsystem, processing subsystem, presenting subsystem, communicating subsystem, research and development, and administrative direction and support.

Where two or more functions were lumped together or a given budget figure is for the support of a multi-purpose activity, e.g., upper air observations, which are used by all categories of meteorology including aviation, proportionate allocations have been made. The basis for each such allocation is discussed in the following sections.

1. The Federal Aviation Agency

The Federal Aviation Agency provides support to the aviation weather service in five of the six categories, all except processing. The cost estimates are presented by subsystems and items within subsystems in the following table. All items except two are self-explanatory.

The first of these is the estimated cost of replacement of equipment, item g, under the communicating subsystem. An annual rate of replacement equal to 10% of the capital investment in equipment has been assumed here. The FAA's total capital investment in equipment used in weather communications is $21, 002, 560, which yields an annual replacement cost of $2, 100, 256.

The second of these items is the estimated cost of administrative direction and support. This item was not included in the cost figures made available by the Agency. As a basis for an estimate, the ratio of the Weather Bureau figures for program management and administrative direction and support to the remainder of the budget was calculated and found to be 10%.

Applying this percentage to the estimated costs to the FAA of all other items, one gets an estimated cost of $2,476,504 for administrative direction and support.

Table 57. Federal Aviation Agency

Item	Description	Basis of Cost Estimate	Man Years	Total Cost
A. Observing Subsystem				
a. Weather measurements	Weather observations are taken once per hour plus at times of significant weather changes at 232 FSS, 14 CS/T, 21 Towers, a total of 267 facilities.	Average time consumed 5 min/hr/facility Average salary plus fringe costs $8,000	105	$840,000
b. Pilot Reports	Pilot reports are received in the normal course of an aircraft contact	No significant increase in workload	0	0
		Sub-Total		$840,000
B. Processing Subsystem	The FAA does not participate in the processing subsystem			
C. Presenting Subsystem				
a. Scheduled Broadcasts (Domestic)	An FSS specialist broadcasts weather information at 15 and 45 minutes past the hour from 407 facilities	Average time consumed 8 min/hr/facility Average salary plus fringe costs $8,000	257	$2,056,000
b. Scheduled Broadcasts (International)	4 IFSS broadcast weather once per hour (VOLMET) by radio	Average time consumed 10 min/hr/facility Total of 3 man years at $8,000	23	144,000
	4 positions at IFSS's continuously broadcast weather (CARMET and WMO) by radio-teletype	4 positions 24 hrs per day equals 20 man year at $6,000	20	120,000
c. Transcribed Weather Broadcasts	Transcribed radio broadcasts are prepared routinely at 80 FSS	Positions in terms of man years equals 80 Average salary plus fringe costs $8,000	80	$1,784,000
d. Pilot Briefing	1,500,000 pilot briefings estimated for fiscal year 1962	Estimated 2 minutes per briefing Average salary plus fringe costs $8,000	27	216,000
		Sub-Total		$4,320,000

Table 57. Federal Aviation Agency (Cont'd.)

Item	Description	Basis of Cost Estimate	Man Years	Total Cost
D. Communicating Subsystem				
a. Transmission of Local Weather	Transmission of hourly weather observations, special observations, SIGMETS and pilot reports from 232 FSS and for 104 WB stations, a total of 336 facilities	Average time consumed 5 min/hr/facility Average salary plus fringe costs $8,000	133	$931,000
b. Collection, Distribution, and Relay				
1. Service A	In addition to hourly weather, etc., 26 FSS perform relay functions for USWB forecast centers	Average time consumed 15 min/hr/facility Average salary plus fringe costs $7,000	31	186,000
	5 ADIS Centers have a total of 16 positions operating 24 hrs/day	Full time Average salary plus fringe costs $7,000	111	480,000
2. Service C	82 FSS transmit basic Service C data received from USWB	Average time consumed 1 hr/day/facility Average salary, adjusted $6,000	16	96,000
	26 FSS transmit Service C forecast data for USWB forecast centers	Average time consumed 3 hr/day/facility Average salary, adjusted $6,000	15	90,000
	2 Service C relay center have a total of 5 positions operating 24 hrs/day	Full time Average salary, adjusted $6,000	25	150,000
3. Service O	5 Service O relay stations have a total of 15 positions on a 24 hr basis	Full time Average salary, adjusted $6,000	75	450,000
	6 Transmitting Stations	Average time consumed 2 hrs/day/facility Average salary, adjusted $6,000	2	12,000

Table 57. Federal Aviation Agency (Cont'd.)

Item	Description	Basis of Cost Estimate	Man Years	Total Cost
c. Leased Landlines	Service A	--	--	1, 371, 189
	Service C	--	--	532, 289
	Service O	--	--	265, 149
d. Radioteletype	66% of all transmissions involve weather data	Man years equals 225 x 66% Average salary, adjusted, $7, 000	149	1, 043, 000
e. Maintenance Service A, C, O	No. of teletype drops Service A 750 Service C 350 Service O 63 1163	Each drop requires 0. 28 man years of maintenance and requires $2, 344 of maintenance funds.	0. 28/ drop	2, 726, 072
	ADIS program requires additional maintenance	Estimated at 59 man years	59	468, 460
	Supply support	--	--	52, 197
f. Maintenance, Point-to-Point and Broadcast(International)	66% of all transmissions involve weather data from 11 IFSS	Annual total maintenance cost is 303 positions and $3, 060, 288	--	2, 019, 790
g. Maintenance, Transcribed Weather Broadcasts	80 Flight Service Stations have transcribed weather broadcast equipment	Each equipment requires 829 man hours of maintenance per year	32	643, 200
h. Maintenance, Pilot-to-Forecaster Equipment	2 experimental Pilot-to-Forecaster installations in operation	Total maintenance estimated at one position	--	8, 440
i. Replacement of Equipment	A portion of communications equipment must be replaced annually due to wear and obsolescence	Estimated replacement rate is 10% per year. Present value of capital investment in equipment is $21, 002, 560		2, 100, 256
		Sub-Total		$13, 625, 042

Table 57. Federal Aviation Agency (Cont'd.)

Item	Description	Basis of Cost Estimate	Man Years	Total Cost
E. Research and Development	The FAA supports a number of research and development programs in the areas of system analysis, system design, data processing and instrumentation	Fiscal year 1962 budget	--	$ 6,100,000
F. Administrative Direction and Support	This includes such functions as executive direction, personnel management, fiscal, procurement and supply, budget, etc.	Total all activities		$24,885,042
		Tentatively estimated as 10% of basic budget		2,488,504
		TOTAL AVIATION WEATHER SUPPORT		$27,373,546

2. The U. S. Weather Bureau

The U. S. Weather Bureau provides support to the aviation weather service in all six categories. The cost estimates by subsystem are presented in the following table.

All Weather Bureau items listed are multi-purpose, i.e., aviation weather support is only one of several functions performed. For example, a typical Weather Bureau Airport Station performs a variety of duties, in addition to aviation support, which may include some or all of the following:

1. General local public forecasting
2. General local public information
3. River forecasting and information
4. Agricultural forecasting and information
5. Local climatological information
6. State/municipal liaison
7. Fire weather forecasting and information

Similarly, weather observations of all types are used in a number of meteorological fields in addition to aviation.

Although the Weather Bureau provides weather support to numerous activities, aviation is without a doubt the biggest user of weather information. Based on conversations with Weather Bureau officials, airline meteorologists, and personal experience, it is estimated that 50% of the Bureau's effort in the categories listed is devoted to the support of the aviation weather service, giving a total amount of $27,864,630.

Various estimates of the percentage of the Bureau's total budget devoted to aviation have been made in recent years, the latest one available being 37%. As a check on the preceding estimate, we will apply this to the total fiscal 1962 budget and obtain the following:

Weather Bureau 1962 Budget

Operations	$56,250,000	
Research & Development	9,000,000	
Equipment	5,250,000	
Total	$70,500,000	37% of Total $26,085,000

This figure is in reasonable agreement with the preceding calculation.

The only item specifically labeled for aviation support is the $573,000 for research to improve the aviation weather services, out of a total R & D budget of $9,000,000. Although the aviation weather service will ultimately derive some benefit from the other programs, no attempt has been made to estimate a proportionate cost figure to be assessed to aviation support.

Table 58. U. S. Weather Bureau Expenditures

Item	Description	Total Positions	Total Costs	Aviation Allocation
A. Observing Subsystem				
a. Surface Observations	Includes observers for 214 full-time stations and 56 part-time stations, 14 marine assistants, and 9 quality control positions	1,227	$ 11,881,900	$ 5,940,950
b. Upper Air Observations	Includes observers for 97 land stations, 33 positions assigned to merchant ships, and 22 positions for reconditioning of instruments and factory inspection	465	7,247,100	3,623,550
c. Radar Observations	Includes support for 30 WSR-57 radar stations and 67 stations equipped with other types of radar	182	1,852,200	926,100
d. Installation, Maintenance and Upkeep	Includes 66 positions assigned to field facility units. 7 substation inspectors and 250 electronic technicians	323	3,047,100	1,523,550
e. Establishment of Meteorological Facilities	Includes purchase and installation of various types of equipment in support of improved weather measuring and forecasting, and construction of office quarters and housing:			
	1. Surface equipment (excluding Climatic and Hydrologic equipment)	--	3,132,000	1,566,000
	2. Upper-air equipment	--	506,000	253,000
	3. Radar equipment	--	486,000	243,000
	4. Engineering and technical support	20	872,000	436,000

Table 58. U. S. Weather Bureau Expenditures (Cont'd.)

Item	Description	Total Positions	Total Costs	Aviation Allocation
f. Program Management	Includes staff in Polar Operations Office, Observations and Station Facilities Division, and Instrumental Engineering Division	84	$ 877,900	$ 438,950
	Sub-Total	2,301	$29,902,200	$14,951,100
B. Processing Subsystem				
a. Data Analysis and Forecasting	Includes support for National Meteorological Center and for field forecast offices.	912	11,790,600	5,895,300
b. Program Management	Positions assigned to Forecasts and Synoptic Reports Division	26*	290.016*	145,008
	Sub-Total	938	12,080,616	6,040,308
C. Presenting Subsystem				
a. Aviation and General Weather Briefing	Includes 575 positions for localization and distribution of forecasts and warnings and 35 positions for quality control	610	5,587,600	2,793,800
	*These positions and total cost were lumped together as a combined program management figure by the F. and S. R. Division of the Processing and Presentation Subsystems. For the purpose of this analysis, the figures have been arbitrarily prorated in the ratio of positions managed, 60% to processing, 40% to presentation			

Table 58. U. S. Weather Bureau Expenditures, (Cont'd.)

Item	Description	Total Positions	Total Costs	Aviation Allocation
b. Program Management	Position assigned to Forecasts and Synoptic Reports Division	21*	$ 193,344*	$ 96,672
		631	5,780,944	2,890,472
D. Communicating Subsystem				
a. Teletypewriter Circuits	Includes charges for RAWARC Hurricane, Local and Administrative circuits, plus staff for communications and editing units at 7 field offices	87	1,700,700	850,350
b. Facsimile Circuits	Includes charges for National and High Altitude Facsimile Circuits plus 5 positions at the National Meteorological Center for transmission of material	5	1,533,100	766,550
c. Program Management	Support for 9 communications specialists attached to Forecasts and Synoptic Reports Division	9	93,700	46,850
	Sub-Total	101	3,327,500	1,663,750
	*These positions and total cost were lumped together as a combined program management figure by the F. & S. R. Division of the Processing and Presentation Subsystems. For the purpose of this analysis, figures have been arbitrarily pro-rated in the ratio of positions managed, 60% to Processing, 40% to Presentation.			

Table 58. U.S. Weather Bureau Expenditures (Cont'd.)

Item	Description	Total Positions	Total Costs	Aviation Allocation
E. Research and Development	Includes that portion of Weather Bureau Research and Development primarily devoted to improving aviation weather services. No prorata factor applied to this item.	25	$ 573,000	$ 573,000
F. Administrative Direction and Support	This includes such functions as executive direction, personnel management, fiscal, procurement and supply printing, budget, etc.	470	$ 3,492,000	$ 1,746,000
	Total, all activities	4,466	$ 55,156,260	$27,864,630

3. **The Military Services**

The Navy and Air Force provide appreciable support to the aviation weather service. This was described in the preceding section but will be briefly summarized here for completeness.

Hourly surface observations from Naval and Marine Corps Air Stations and Air Force Bases are available on the Service A Teletype Network

Aerial weather reconnaissance observations and pilots reports from military aircraft are relayed to the service.

Radar weather observations from military air bases are available

Surface and upper air observations from Naval vessels at sea are transmitted to civil users.

Routine upper air observations from two Air Force Bases and non-scheduled upper air observations from a number of military bases are placed on Service C teletype for civil use

Numerous weather reports from Air Force Bases are collected by the Air Force teletype system and relayed to the civil circuits. Naval communications are utilized in collecting observations from ships at sea and outlying stations.

Results from the many research and development programs sponsored and conducted by the military services are utilized by the aviation weather service.

All the activities listed above are performed by the military services solely in support of military operations. The considerable benefits derived by civil users are incidental to the primary missions which they support. Accordingly, no costs for these primarily military services have been allocated to the aviation weather service.

The total military expenditures on all weather services including aviation are listed below:

TOTAL ESTIMATED EXPENDITURES, FY'62

Service	Operations	R & D	Total
Army	$ 1,040,000	$7,140,000	$ 8,180,000
Navy	25,240,000	3,140,000	28,380,000
Air Force	73,330,000	8,700,000	82,030,000

Table 59. Participation, Financial and Operational, by Agencies in Present Aviation Weather Services

Function	Weather Bureau	Federal Aviation Agency	U. S. Navy	U. S. Air Force	U. S. Army
Observing Subsystem	Yes $14,951,000	Yes $ 840,000	*Yes	*Yes	*Yes
Processing Subsystem	Yes $ 6,040,308	No	No	No	No
Presenting Subsystem	Yes $ 2,890,472	Yes $4,320,000	No	No	No
Communicating Subsystem	Yes $ 1,663,750	Yes $13,625,042	*Yes	*Yes	No
Research and Development	Yes $ 473,000	Yes $6,100,000	*Yes	*Yes	*Yes
Administrative Direction and Support	Yes $ 1,746,000	Yes $2,488,504	*Yes	*Yes	*Yes
Total	$27,864,630	$27,373,546	None Allocated	None Allocated	None Allocated
Grand Total	$55,238,176				

*No cost to civil aviation weather service; function performed as part of military mission.

PART III

COST-BENEFIT ANALYSIS

PART III

COST-BENEFIT ANALYSIS

A. ESTIMATED COST OF IMPLEMENTATION OF THE COMMON AVIATION WEATHER SYSTEM

1. General Considerations

2. Cost Summary

3. Costs by Subsystems

   a. Presentation
   b. Processing
   c. Observing
   d. Communications

B. ESTIMATED DOLLAR BENEFITS

1. General Aviation

   a. Accidents
   b. Delays

2. Air Carriers

   a. Cancellations
   b. Delays
   d. Alternate Fuel, Contingency, Pilot's Contingency

3. ATC System and User Delays

C. NET BENEFIT ANALYSIS

1. General Considerations

2. Present Value of Capital Investments

3. Present Value of Net Benefits

4. Intangible Benefits

A. ESTIMATED COSTS OF IMPLEMENTATION OF THE COMMON AVIATION WEATHER SYSTEM

1. General Considerations

In estimating the costs of implementing the CAWS, the phasing schedule contained in Report No. 2, Common Aviation Weather System Development Program, was used as a basis for calculating costs by years. The schedule is reproduced here as Figure 27.

Instrument costs, communication costs and staffing figures were obtained from FAA and Weather Bureau reports and the Bureau of the Budget Report "Survey of Federal Meteorological Activities, March 1962".

Computer costs for the various levels of processing were obtained from estimates prepared by the Travelers Research Center.

2. Summary

A summary of estimated costs by years by subsystems broken down into capital expenditures and annual recurring costs is given in Table 60. It can be seen that the major capital costs are programmed for the years 1965-1967; the annual operating costs increase progressively, reaching a constant level by 1970.

To permit a direct comparison of costs and benefits, the final estimates of annual costs of operation and maintenance of the system have been increased at an annual rate of 2-1/2%, since these costs are primarily salaries. This follows the same line of reasoning used in increasing the estimates of passenger salaries by the annual amount in estimating potential benefits[1].

---

[1] See pgs. 24, 25

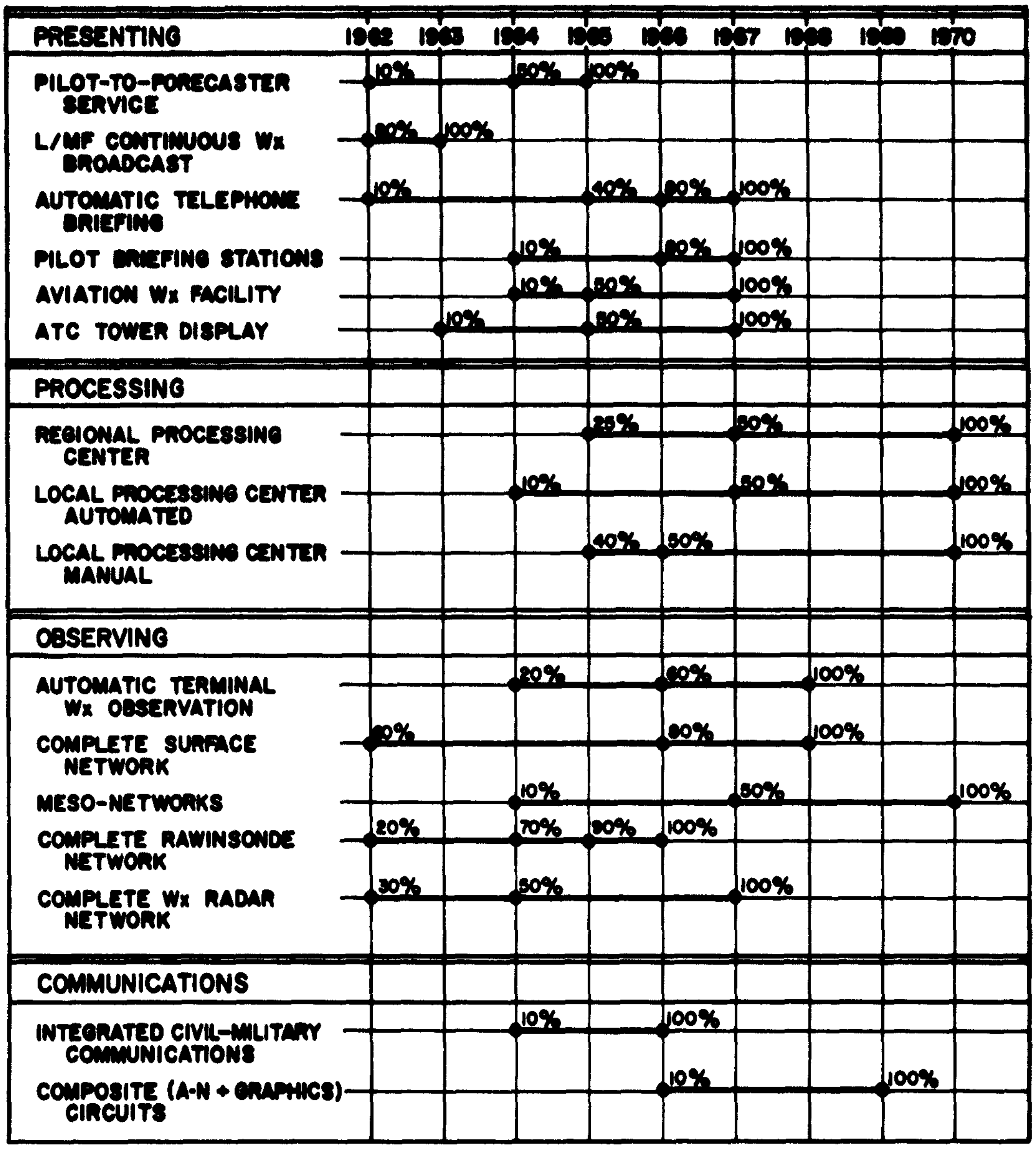

FIGURE 27. CAWS IMPLEMENTATION PLAN

Table 60. Estimated Implementation Costs (in millions)

	Equipment				Salaries, Maintenance, etc.					
Year	Pres.	Proc.	Obs.	Total	Pres.	Proc.	Obs.	Total	2-1/2% Annual Increase	Total Equipment Salaries
1962	$0.91	0	2.80	3.71	2.29	0	2.63	4.92	5.04	8.75
1964	4.04	0	6.79	10.83	5.73	1.54	6.20	13.48	14.16	24.99
1965	10.04	0.05	7.84	17.93	10.97	5.83	9.45	26.25	28.22	46.15
1966	14.55	0.10	13.05	27.70	22.58	7.27	15.78	45.65	50.20	77.90
1967	7.50	0.10	13.01	20.61	28.53	13.83	21.56	63.92	71.91	92.52
1968	0	0.10	6.85	6.95	28.53	15.27	24.58	68.38	78.63	85.58
1969	0	0.10	1.96	2.07	28.53	21.82	26.63	76.98	90.45	92.52
1970	0	0.10	1.23	1.33	28.53	28.37	26.87	83.78	100.13	101.46
1971	0	0	0	0	28.53	28.37	26.87	83.78	102.17	102.17
1972	0	0	0	0	28.53	28.37	26.87	83.78	104.21	104.21
1973	0	0	0	0	28.53	28.37	26.87	83.78	106.25	106.25
1974	0	0	0	0	28.53	28.37	26.87	83.78	108.29	108.29
1975	0	0	0	0	28.53	28.37	26.87	83.78	110.33	110.33

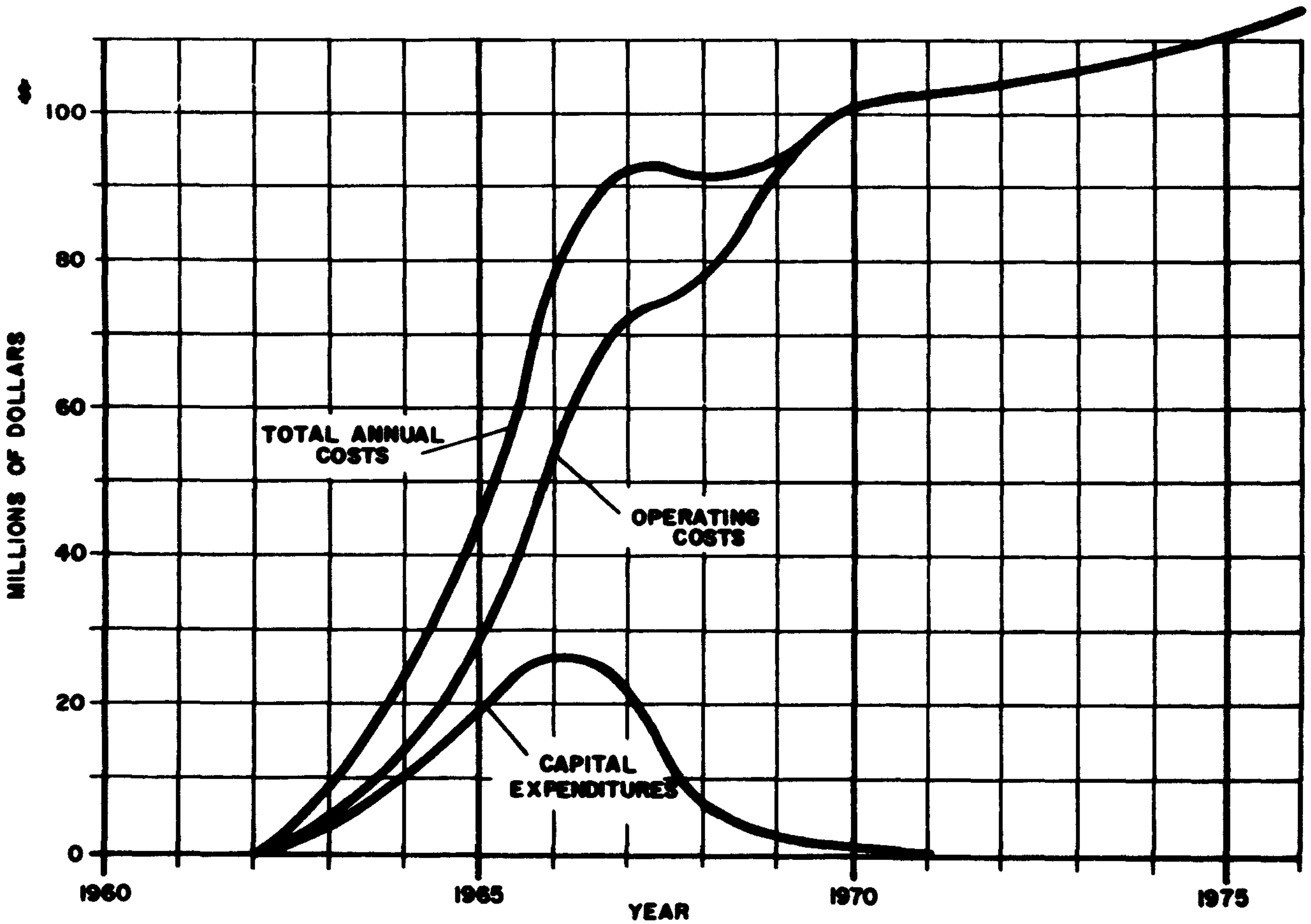

FIGURE 28. ESTIMATED IMPLEMENTATION COST IN MILLIONS OF DOLLARS

3. Costs by Subsystem

a. Presentation

(1) Pilot-to-Forecaster (15)

Washington experimental unit used as a basis.

Equipment	$ 38,770
Salaries	$102,000
Operations and Maintenance	$ 14,600

The preliminary design calls for a total of 100 pilot-to-forecaster installations to cover the United States. In addition to the two existing and three programmed civil units, the military operates over 100 pilot-to-forecaster units.

Assuming that these military units will become part of the CAWS, it is estimated that an additional 15 units will be required to provide adequate coverage since the military units were established to serve particular bases rather than to provide a nationwide coverage.

(2) L/MF Continuous Weather Broadcast (20)

Equipment	$ 8,380
FAA estimates 2.8 man years per station GS-9 base times 1.24 for fringe benefits	$ 8,000
Salaries 2.8 x $8,000	$ 22,400
Operation and Maintenance 0.4 man years per stations	$ 3,376

(3) **Automatic Telephone Briefing** (635)

Equipment estimated at	$10,000
Salaries, 3 man yrs.	$25,000
Operations and Maintenance at 40% 10,000 x .40	$ 4,000

(4) **Pilot Briefing Stations**

(a) Terminal Status Map (150 major terminals)

Equipment estimated at	$10,000
Maintenance at 20%	$ 2,000

(b) Briefing Equipment (750)

Forecast Printer	$20,000
Graphics Projector	$10,000
Terminal Weather Indicator	$ 2,000
Equipment Total	$32,000
Maintenance at 20%	$ 6,400

(5) **Aviation Weather Facility (20 ATC centers)**

Equipment cost	$150,000
Salaries	$100,000
Maintenance at 20%	$ 30,000

(6) **ATC Tower Displays (750 towers)**

Equipment cost	$ 2,000
Maintenance at 20%	$ 400

Table 61. Presenting Subsystem

Presentation	Equipment Costs			Annual Costs					
Item	No. of New Installations	Unit Cost of Hardware, Shipping, etc.	Total	Total No. Installations	Unit Salaries	Unit Operation and Maintenance	Unit Total	Total Recurring Cost	Total Costs this Year
Pilot-to-Forecaster	(5)								
1963	5	38,770	193,850	5	102,000	14,600	116,600	583,000	776,850
1964	5	38,770	193,850	10	102,000	14,600	116,600	1,166,000	1,359,850
1965	5	38,770	193,850	15	102,000	14,600	116,600	1,749,000	1,942,850
1966 to 1975	0	0	0	15	102,600	14,600	116,600	1,749,000	1,749,000
LMF Broadcast	(80)								
1963	20	8,380	167,600	20	22,400	3,376	25,776	515,500	683,100
1964 to 1975	0	0	0	20	22,400	3,376	25,776	515,500	515,500
Automatic Telephone Briefing	(115)								
1963	40	10,000	400,000	40	25,000	4,000	29,000	1,160,000	1,560,000
1964	70	10,000	700,000	110	25,000	4,000	29,000	3,190,000	3,890,000
1965	70	10,000	700,000	180	25,000	4,000	29,000	5,220,000	5,920,000
1966	300	10,000	3,000,000	480	25,000	4,000	29,000	13,920,000	16,920,000
1967	150	10,000	1,500,000	630	25,000	4,000	29,000	18,270,000	19,770,000
1968 to 1975	0	0	0	630	25,000	4,000	29,000	18,270,000	18,270,000
Pilot Briefing Stations									
(a) Terminal Status Map (major terminals only)									
1964	15	10,000	150,000	15	0	2,000	2,000	30,000	180,000
1965	45	10,000	450,000	60	0	2,000	2,000	120,000	570,000
1966	60	10,000	600,000	120	0	2,000	2,000	240,000	840,000
1967	30	10,000	300,000	150	0	2,000	2,000	300,000	600,000
1968 to 1975	0	0	0	150	0	2,000	2,000	300,000	300,000

Table 61. Presenting Subsystem (Cont'd.)

Presentation (Cont'd.)	Equipment Costs			Annual Costs					
Item	No. of New Installations	Unit Cost of Hardware, Shipping, etc.	Total	Total No. Installations	Unit Salaries	Unit Operation and Maintenance	Unit Total	Total Recurring Cost	Total Costs this Year
Pilot Briefing Stations (cont'd.)									
(b) Briefing Equipment									
1964	75	32,000	2,400,000	75	0	6,400	6,400	480,000	2,880,000
1965	225	32,000	7,200,000	300	0	6,400	6,400	1,920,000	9,120,000
1966	300	32,000	9,600,000	600	0	6,400	6,400	3,840,000	13,440,000
1967	150	32,000	4,800,000	750	0	6,400	6,400	4,800,000	9,600,000
1968 to 1975	0	0	0	750	0	6,400	6,400	4,800,000	4,800,000
ATC Tower Display									
1963	75	2,000	150,000	75	0	400	400	30,000	180,000
1964	150	2,000	300,000	225	0	400	400	90,000	390,000
1965	150	2,000	300,000	375	0	400	400	150,000	450,000
1966	225	2,000	450,000	600	0	400	400	240,000	690,000
1967	150	2,000	300,000	750	0	400	400	300,000	600,000
1968 to 1975	0	0	0	750	0	400	400	300,000	300,000
Aviation Weather Facility									
1964	2	150,000	300,000	2	100,000	30,000	130,000	260,000	560,000
1965	8	150,000	1,200,000	10	100,000	30,000	130,000	1,300,000	2,500,000
1966	6	150,000	900,000	16	100,000	30,000	130,000	2,080,000	2,980,000
1967	4	150,000	600,000	20	100,000	30,000	130,000	2,600,000	3,200,000
1968 to 1975	0	0	0	20	100,000	30,000	130,000	2,600,000	2,600,000

b. Processing

(1) Processing Centers

Computer rental plus programmer's salaries estimates made by Travelers Research Center. Estimates are based on a cost per instruction for an IBM 7044 computer and are normalized to a 75% utilization. The total annual figure for the entire processing subsystem is estimated to be $15, 840, 000.

The hours of utilization per day were used to estimate the costs for each of the three types of processing centers with the following results:

National	$1, 083, 000
Regional	$ 547, 500
Local	$ 627, 500

(a) National Processing Center

It is estimated that present and planned staffing and computer capacity of the NMC, Suitland, Md., are adequate to meet all the CAWS requirements. Implementation of the CAWS will involve no additional expense.

(b) Regional Processing Center (4)

The FAWS unit at Idlewild, New York, was used as a basis for estimating staffing requirements for regional processing centers. Assuming an average GS-11 base plus 25% gives $9, 375 per man year. Annual salaries equal 68 x $9, 375 = $637, 500. Maintenance was estimated at 10% of personnel costs - $63, 750.

(c) Local Processing Center, Automated (20)

A standard FAWS unit was used as the basis for estimating the staffing requirements for local processing centers. Assuming an average GS-11 base plus 25% gives $9, 375 per man year. Annual salaries

equal 14 x 9375 = $131, 250. Maintenance was estimated at 10% of salaries, . 10 x $131, 250 = $13, 125.

The salaries of programming personnel are included in computer cost estimates.

(d) Local Processing Center, Manual (55)

A standard FAWS unit was used as the basis for estimating the staffing. Assuming an average GS-11 base plus 25% gives $9375 per man year. Annual salaries equal 14 x $9375 = $131, 250.

Maintenance was estimated at 10% of salaries, . 10 x $131, 250 = $13, 125.

Furniture, etc., estimated at $10, 000 per unit.

Table 62. Processing Subsystem

Processing

Item	No. of New Installations	Unit Computer Costs	Total Computer Costs	Total No. of Installations	Unit Salaries	Unit Operation and Maintenance	Unit Total	Total Recurring Costs	Total This Year
<u>Regional Processing Center</u>									
1965	1	547,500	547,500	1	637,500	63,750	701,250	701,250	1,248,750
1966	0	547,500	547,500	1	637,500	63,750	701,250	701,250	1,248,750
1967	1	547,500	1,095,000	2	637,500	63,750	701,250	1,402,500	2,497,500
1968	0	547,500	1,095,000	2	637,500	63,750	701,250	1,402,500	2,497,500
1969	1	547,500	1,642,500	3	637,500	63,750	701,250	2,103,750	3,746,250
1970	1	547,500	2,190,000	4	637,500	63,750	701,250	2,805,000	4,995,000
1971 to 1975	0	547,500	2,190,000	4	637,500	63,750	701,250	2,805,000	4,995,000
<u>Local Processing Centers, Automated</u>									
1964	2	627,500	1,255,000	2	131,250	13,125	144,375	288,750	1,543,750
1965	3	627,500	1,137,500	5	131,250	13,125	144,375	721,875	3,859,375
1966	0	627,500	3,137,500	5	131,250	13,125	144,375	721,875	3,859,375
1967	5	627,500	6,275,000	10	131,250	13,125	144,375	1,443,750	7,718,750
1968	0	627,500	6,275,000	10	131,250	13,125	144,375	1,443,750	7,718,750
1969	5	627,500	9,412,500	15	131,250	13,125	144,375	2,165,625	11,578,125
1970 to	5	627,500	12,550,000	20	131,250	13,125	144,375	2,887,500	15,437,500
1975	0	627,500	12,550,000	20	131,250	13,125	144,375	2,887,500	15,437,500
<u>Local Processing Centers, Manual</u>									
1965	5	10,000	50,000	5	131,250	13,125	144,375	721,875	771,875
1966	10	10,000	100,000	15	131,250	13,125	144,375	2,165,625	2,265,625
1967	10	10,000	100,000	25	131,250	13,125	144,375	3,609,375	3,709,375
1968	10	10,000	100,000	35	131,250	13,125	144,375	5,053,125	5,153,125
1969	10	10,000	100,000	45	131,250	13,125	144,375	6,496,875	6,596,875
1970 to	10	10,000	100,000	55	131,250	13,125	144,375	7,940,625	8,040,625
1975	0	0	0	55	131,250	13,125	144,375	7,940,625	8,040,625

c. **Observing**

(1) **Complete installation of automatic observing equipment at 300 manual observing stations.**

Transmissometer	
Basic hardware	$ 3,600
Cable	800
Shipping	500
Installation	4,000
	$ 8,900
RVR Computer	
Basic hardware	$ 3,600
Shipping	100
Installation	1,300
	$ 5,000
Rotating Beam Ceilometer	
Basic hardware	$ 6,900
Cable	1,000
Shipping	450
Installation	3,750
	$12,100
Wind-Temperature	
Basic hardware	$ 8,200
Cable	1,000
Shipping	200
Installation	3,900
	$13,300
Total per installation	$39,300

Annual maintenance estimated at 20% of capital costs - $7,860 per year.

(2) Increase 200 Part Time Observing Stations to Full Time

This will require 2 additional observers per station. Assuming an average GS-6 base plus 25%, gives $6,000 per year times 2 = $12,000 per station.

(3) Provide Digital Readout From Automatic Observing Equipment at 600 Stations

Basic hardware	$10,000
Shipping	100
Installation	1,500
Modification to RBC	1,000
Total per station	$12,600

Maintenance estimated at 20% of capital cost = $2,520

(4) Provide 200 Additional Manual Observing Stations

Basic hardware	$ 5,500
Shipping	100
Installation	9,300
Total	$14,900

Operation and maintenance estimated at 40% of capital costs = $5,980 per year.

A full time observing station has a complement of 5 observers. Assuming an average GS-6 base plus 25% gives $6,000 times 5 men = $30,000 per year.

(5) Installation of Mesonetworks at 20 Major Terminals

It is assumed that the central station of each network will be a fully automated station, the costs of which have been included elsewhere. The mesonetwork will be comprised of the central station and 12 automated satellite stations taking measurements of:

- Wind speed and direction
- Transmissivity
- Temperature
- Cloud height
- Dew point

Equipment required for each satellite station:

<u>Transmissometer</u>	
Basic hardware	$ 3,600
Cable	800
Shipping	500
Installation	4,000
Total	$ 8,900
<u>Rotating Beam Ceilometer</u>	
Basic hardware	$ 6,900
Cable	1,000
Shipping	400
Installation	3,700
	$12,000
<u>Wind-temperature</u>	
Basic hardware	$ 8,200
Cable	1,000
Shipping	200
Installation	3,900
Total	$13,300
Total per Satellite Station	$34,200
Total per Meso-Network	$410,000

(6) **Expand 52 Rawinsonde Stations to 4 Observations Per Day**

This requires 3 additional meteorological technicians per station. Assuming GS-9 base plus 25% equals $8,000 x 3 = $24,000 per year. Expendables estimated at $5,000 year.

(7) **31 New Rawinsonde Stations**

Equipment

(a) Radiotheodolite

Basic hardware	$46,400	
Cable	1,500	
Shipping	1,000	
Installation	1,500	
Total	$50,400	

(b) Transponder

Basic hardware	$13,600	
Shipping	350	
Installation	2,450	
Total	$16,400	
Total per station		$66,800

Current staffing for four observations per day is 7 meteorological technicians. Assuming average GS-9 base plus 25% gives $8,000 x 7 = $56,000 per year.

Annual operation and maintenance estimated at 20% of capital costs - $13,360.

(8) **Complete Long Range Weather Radar Network (68 stations)**

Weather Radar (WSR-57)

Basic hardware (includes 2-way microwave 75,000, tower $6,000., and dome $5,000)	$211,000
Cable	4,000
SH pping	3,000

Installation	$ 90,000
Total per station	$308,000

Current staffing of WSR-57 installations is 5 radar meteorologists. Assuming average GS-9 base plus 25% gives $8,000 times 5 = $40,000 per year.

Maintenance estimated at 20% of capital costs equals $61,600 per year.

Table 63. Observing Subsystem

Observing

Item	No. of New Installations	Unit Cost of Equipment, etc.	Total	Total No. of Installations	Unit Salaries	Unit Operation and Maintenance	Unit Total	Total Recurring Costs	Total This Year
Automatic Terminal Weather Observations									
1964	60	39,300	2,358,000	60	0	7,860	7,860	471,600	2,829,600
1965	60	39,300	2,358,000	120	0	7,860	7,860	943,200	3,301,200
1966	60	39,300	2,358,000	180	0	7,860	7,860	1,414,800	3,772,800
1967	60	39,300	2,358,000	240	0	7,860	7,860	1,886,400	4,244,400
1968	60	39,300	2,358,000	300	0	7,860	7,860	2,358,000	4,716,000
1969 to 1975	0	0	0	300	0	7,860	7,860	2,358,000	2,358,000
Increase Part Time Stations to Full Time									
1963	60	0	0	60	12,000	0	12,000	720,000	720,000
1964	60	0	0	120	12,000	0	12,000	1,440,000	1,440,000
1965	60	0	0	180	12,000	0	12,000	2,160,000	2,160,000
1966	60	0	0	240	12,000	0	12,000	2,880,000	2,880,000
1967 to 1975	60	0	0	300	12,000	0	12,000	3,600,000	3,600,000
Digital Readout									
1964	10	12,600	126,000	10	0	2,520	2,520	25,200	151,200
1965	40	12,600	504,000	50	0	2,520	2,520	126,000	630,000
1966	150	12,600	1,890,000	200	0	2,520	2,520	504,000	2,394,000
1967	200	12,600	2,520,000	400	0	2,520	2,520	1,008,000	3,528,000
1968	200	12,600	2,520,000	600	0	2,520	2,520	1,512,000	4,032,000
1969 to 1975	0	0	0	600	0	2,520	2,520	1,512,000	1,512,000

Table 63. Observing Subsystem (Cont'd.)

Observing (Cont'd.)

Item	No. of New Installations	Unit Cost of Equipments, etc.	Total	Total No. of Installations	Unit Salaries	Unit Operation and Maintenance	Unit Total	Total Recurring Costs	Total This Year
Manual Surface Obs. Stations									
1966	50	14,900	745,000	50	30,000	5,980	35,980	1,799,000	2,544,000
1967	50	14,900	745,000	100	30,000	5,980	35,980	3,598,000	4,343,000
1968	50	14,900	745,000	150	30,000	5,980	35,980	5,397,000	6,142,000
1969	50	14,900	745,000	200	30,000	5,980	35,980	7,196,000	7,941,000
1970 to 1975	0	0	0	200	30,000	5,980	35,980	7,196,000	7,196,000
Mesonetworks									
1964	2	410,000	820,000	2	0	82,000	82,000	164,000	984,000
1965	3	410,000	1,230,000	5	0	82,000	82,000	410,000	1,640,000
1966	3	410,000	1,230,000	8	0	82,000	82,000	656,000	1,886,000
1967	3	410,000	1,230,000	11	0	82,000	82,000	902,000	2,132,000
1968	3	410,000	1,230,000	14	0	82,000	82,000	1,148,000	2,378,000
1969	3	410,000	1,230,000	17	0	82,000	82,000	1,394,000	2,624,000
1970	3	410,000	1,230,000	20	0	82,000	82,000	1,640,000	2,870,000
1971 to 1975	0	0	0	20	0	82,000	82,000	1,640,000	1,640,000
Upper Air Obs. Expand to 4 per day									
1963	0	0	0	26	24,000	5,000	29,000	754,000	754,000
1964 to 1975	0	0	0	52	24,000	5,000	29,000	1,508,000	1,508,000
Upper Air Observing Stations									
1963	5	66,800	334,000	5	56,000	13,360	69,360	346,800	680,800
1964	6	66,800	400,800	11	56,000	13,360	69,360	762,960	1,163,760
1965	10	66,800	668,000	21	56,000	13,360	69,360	1,456,560	2,124,560
1966 to	10	66,800	668,000	31	56,000	13,360	69,360	2,150,160	2,818,160
1975	0	0	0	31	56,000	13,360	69,360	2,150,160	2,150,160

Table 63. Observing Subsystem (Cont'd.)

Observing (Cont'd.)

Item	No. of New Installations	Unit Cost of Equipment, etc.	Total	Total No. of Installations	Unit Salaries	Unit Operations and Maintenance	Unit Total	Total Recurring Costs	Total This Year
<u>Weather Radar Network</u>									
1963	8	308,000	2,464,000	8	40,000	61,600	101,600	812,800	3,276,800
1964	10	308,000	3,080,000	18	40,000	61,600	101,600	1,828,800	4,908,800
1965	10	308,000	3,080,000	28	40,000	61,600	101,600	2,844,800	5,924,800
1966	20	308,000	6,160,000	48	40,000	61,600	101,600	4,876,800	11,036,800
1967	20	308,000	6,160,000	68	40,000	61,600	101,600	6,908,800	13,068,800
1968	0	0	0	68	40,000	61,600	101,600	6,908,800	6,908,800

d. Communications

It has not proven possible to estimate the cost of the implementation of the CAWS communication subsystem in the amount of detail or with the degree of confidence that was possible in the case of the other three subsystems. The communication subsystem exists for the purpose of transferring information, without alteration, between the other three subsystems. As a result, design of the communication subsystem in sufficient detail for reasonably accurate cost analysis must follow more detailed design of the other three subsystems.

The preliminary design of the CAWS specifies that the communication subsystem will be comprised of the following communication links:

- A nationwide meteorological teletype circuit
- A nationwide meteorological graphics circuit
- Hub collection circuits in each hub area
- A nationwide operational teletype circuit
- A nationwide operational graphics circuit
- Local circuits in major terminal areas
- Nationwide continuous weather broadcast coverage
- Nationwide pilot-to-forecaster radio coverage
- Nationwide telephone briefing coverage.

Cost estimates for implementing the last three items have been included under the presentation subsystem and will not be repeated here.

The preliminary design includes the following circuits:

- A 3 Kc nationwide meteorological circuit carrying 1000 wpm alpha-numeric and 120 scan graphics products
- A 3 Kc nationwide operational circuit carrying 1000 wpm alpha-numeric and 120 scan graphics products
- 100 wpm teletype hub collection circuits in each hub area

In estimating the costs, the following assumptions have been made:

Cost of facsimile receiver	\$3000
Cost of 1000 wpm teletype receiver	\$5000
Cost of 100 wpm teletype receiver	\$1500
Rental of 3 Kc transmission line	\$3/mo/mile
Rental of 300 cycle transmission line	\$1.50/mo/mile
Cost of receivers amortised over 10 years	
Annual maintenance equals 20% of capital cost	

<u>Meteorological Circuit</u>

1. Facsimile	
120 receivers at \$3000 = \$360,000	
annual cost at 10%	\$36,000
Annual maintenance at 20%	\$72,000
Total annual cost	\$108,000
2. Teletype	
120 receivers at \$5,000 = \$360,000	
annual cost at 10%	\$36,000
Annual maintenance at 20%	\$120,000
Total annual cost	\$180,000
3. Line Rental	
20,000 miles at \$3/mo/mile	\$720,000
Total annual operating cost	\$1,008,000

<u>Operational Circuit</u>

1. Facsimile	
750 receivers at \$3,000 = \$2,250,000	
annual cost at 10%	\$225,000
Annual maintenance at 20%	\$450,000
Total annual cost	\$675,000

2.	Teletype	
	750 receivers at $5000 = 3,750,000	
	annual cost at 10%	$375,000
	Annual maintenance at 20%	$750,000
	Total annual cost	$1,125,000
3.	Line Rental	
	50,000 miles at $3/month/mile	$1,800,000
	Total annual operating cost	$3,600,000

Hub Collection Circuits

1.	1000 send/receive teletypes	
	at $1500=$1,500,000	$150,000
	annual cost at 10%	
	Annual maintenance at 20%	300,000
	Total Cost	$450,000
2.	Line rental 50,000 miles at	
	$1.50/month/mile	$900,000
	Total annual operating cost	$1,350,000

Summation - costs per year	
Meteorological Circuit	$1,008,000
Operational circuit	3,600,000
Hub Collection Circuits	1,350,000
Grand Total	$5,958,000

Cost of Present Aviation Weather Communication Services

FAA (Service A & C)

Maintenance	$3,111,449
Leased lines	1,903,478
Capital costs (10%)	1,771,500
Total	$6,786,427

This sum is ~40% of the total FAA expenditures on weather communications. Since only the total expenditures are known for the Weather Bureau and Air Force, this percentage figure will be applied in estimating the portion of the present Weather Bureau and Air Force expenditures on weather communications which will be replaced by the CAWS.

U. S. Weather Bureau	
Facsimile, RAWARC, etc.	$3,400,000
Maintenance, etc. at 40%	1,360,000
U. S. Air Force	
1R, 1L circuits	
Global total	$13,540,000

The U. S. portion of Air Force Weather Communications is estimated by the Bureau of the Budget at 52% = $7,040,000

Maintenance, operation, etc. at 40%	$2,816,000

It is estimated that 75% of this will be replaced by the CAWS. The remainder will still be necessary to meet requirements peculiar to Air Force operations.

at 75%	$2,112,000
Recapitulation	
FAA	$6,786,427
USWB	1,360,000
USAF	2,112,000
Grand Total	$10,258,427
Total to be replaced by CAWS	$10,258,000
Annual cost of CAWS circuits	5,958,000
Apparent savings	$4,300,000

The estimates of costs for the CAWS are undoubtedly low since they do not include provision for local circuits nor the distribution of rapid cycle observations from Air Force Bases. In any event, it is safe to say that implementation of the CAWS communication subsystem will not involve any additional expenditures over the present weather communications, and may actually result in reduced costs.

B. ESTIMATED DOLLAR BENEFITS

B. ESTIMATED DOLLAR BENEFITS

1. General Aviation

a. Accidents

There are two main types of general aviation accidents in which weather is a factor, viz:

(1) Minor accidents while landing, taking off or taxiing in a gusty wind, cross-wind or downwind. The immediate cause of these accidents is pilot technique. Improved weather information would result in a negligible decrease in this type of accident.

(2) Fatal accidents which are, with very minor exceptions, all of one type, i.e., a non-instrument rated pilot attempts to continue VFR flight after encountering IFR conditions. In descending order of frequency the weather information obtained by the pilot prior to the flight may be classified as follows:

- No weather briefing received.
  This may be due to a number of causes such as non-availability of briefing or difficulty of access to briefing facility either in person or by telephone; lack of suitable radio receiving equipment, or inadequate pilot training.

- Adequate weather briefing received but disregarded due to lack of training, misunderstanding, or desire to reach a given destination by a specified time.

- Inadequate or erroneous weather briefing received. This case appears to be the exception.

In all these cases it is the lack, misuse or misunderstanding of weather information in flight planning which causes the accident. Improvements in the accuracy, timeliness, availability and understandability of weather information should produce a corresponding decrease in these fatal accidents although it is too much to expect that they will be completely eliminated.

It is reasonable to state that the majority of these pilots could have been saved through one or several of the following features.

- Better availability of weather information
- More accurate enroute and terminal forecasts
- More operationally oriented forecasts
- More thorough pilot training, especially in Aviation Meteorology.

Among the improvements contained in the CAWS design, particularly those pertaining to the presenting subsystem, many are specifically applicable to use by the general aviation pilots. A number of these are listed below:

- Establishment of a large number of automatic telephone weather briefing facilities
- Establishment of additional transcribed continuous weather broadcasts
- Establishment of pilot-to-forecaster stations
- Standardization of briefing situations, procedures, facilities, and formats.

The official summaries of general aviation accident reports, due to lack of detailed descriptions of the causes of fatal general aviation accidents, do not provide a feasible method to determine to what extent or percentage the above mentioned causal factors contributed to the accidents. A study of each accident report would be beyond the scope of this project. As an illustration of this point, a sampling of 1300 randomly chosen general aviation accident reports[1]

[1] CAB, Summaries of General Aviation Accidents, 1959-1960.

was made covering the period 1959-1960. From this sample 87 fatal accidents were identified which occurred enroute or in the approach and where non-instrument rated pilots either:

> stayed below the clouds and kept flying into lowering ceilings until forced to crash land or collided with rising terrain,
>
> or
>
> lost control after flying into IFR weather and crashed.

In approximately 70% of these cases the only known fact was that the pilot encountered IFR weather. Thus, more than two-thirds of these casualties could not be categorized as to specific weather causes. An analysis of general aviation weather fatalities as to causal factors can therefore not be undertaken without studying the individual accident reports.

The approach taken here to estimate the number of lives that could be saved in general aviation as a result of the improvements in the weather services, follows a process of elimination. It is clear that the improvements would benefit all general aviation pilots, those who fly without mishap, those who experience narrow escapes. They also would have averted many of the present casualties.

The impact of the improvements on the first two groups must primarily be measured in terms other than economics. These groups will undertake their flights with a greater confidence factor. The one tangible economic gain will be the reduction in delays which has been treated elsewhere in this report. However, the impact on the third group, the fatalities, will be assessed as an economic benefit based on the assigned dollar value of the economic loss resulting per fatality.

A large majority of this group presently obtains no weather briefing at all, owing to the fact that out of 6835 airports used by General Aviation[1] only 468 have aviation weather briefing facilities[2]. This constitutes approximately 7%

[1] Statistical Study of U.S. Civil Aircraft, Jan. 1961, FAA
[2] FAA Air Traffic Activity, Fiscal Year 1961

However, more than 7% of the general aviation pilots are covered since many of the 468 airports are located at or near major hub areas, which cover a proportionately larger share of General Aviation flying.

The large majority of pilots who do not receive adequate weather briefings or who cannot obtain a briefing is expected to benefit materially from the nationwide availability of more operational and updated weather information as a result of the planned improvements. There is no direct way, of course, to predict how many of these pilots will actually make use of this information except that through expanded nationwide weather display and presentation facilities practically all general aviation pilots will have this information readily available by 1975. As the reliability and availability of weather forecasts increase, it appears likely that their use will increase at least correspondingly.

There is, however, in every group a certain percentage who will act against advice, thus who will take-off in the face of an unfavorable weather forecast, or who will not avail themselves of the weather briefings offered. The sise of this group cannot be ascertained exactly but can only be estimated, particularly since the planned improvements in aviation weather services have yet to be implemented.

To obtain a reasonable basis for such an estimate, comparable figures as to the effect of instruction and traffic information on automobile driver violations and accidents may be cited here. Various studies in this field[1] indicate that proper instruction and information reduces violations and accidents on the average by a factor of 50%, i.e., after proper instruction only half of all drivers are found to have violations.

While traffic instruction and information is not directly comparable to weather instruction and information given to pilots, it is considered sufficiently related that it will be used as a first approximation. Thus, if that

[1] American Automobile Association Data, 10 Year Study of State of Pennsylvania Study made by All-State Insurance Company, Conf. with Dr. Deal, California State Dept. of Education, July 31, 1962.

group of pilots, who presently become weather casualties, were to receive adequate weather briefings and instructions, one half could be expected to act on these instructions, stay on the ground, and not expose themselves to unfavorable flight weather conditions. This group comprising 50% will be considered saved from an accident.

The remaining 50% will not receive weather briefings for various reasons, or will not avail themselves of advice and will take-off inspite of an unfavorable weather forecast. A portion of this group will experience narrow escapes or encounter weather enroute and at the terminal better than the forecast specified.

To arrive at an estimate of this number it must be ascertained what degree of forecasting accuracy is presently obtained and can reasonably be expected in the 15 year period ahead. A recent study of forecast verification[1] finds, that of a total of 6920 forecasts sampled predicting less than VFR conditions (below 1000' ceiling and 3 mile visibility, valid for a 6 hr. period) at 17 nationwide terminals, 2938 forecasts turned out to be erroneous, i.e., the terminal had high VFR conditions. This is a ratio of 42%. Thus 42 times out of every 100 forecasts, predicting less than VFR weather, the conditions were actually observed to be above VFR at the terminal. This is a surprisingly high percentage. However, it must be considered here that the forecasts concerned only terminal conditions and not enroute weather. Had the verification been made over the entire flight leg this ratio of 42% incorrect forecasts would have been reduced considerably. Frequently, even though the terminals are above VFR minimums, points enroute are below minimums, rendering VFR flying hazardous. A reduction of the error probability from 42% to 30% is conservative and would apply to present forecasting accuracy. Improved forecasting methods are expected to lower this figure to 20%.

[1] "Quantitative Assessment of the Performance Characteristics of the Airways Terminal Forecasting System" by R. E. Kerr, Jr., John R. Thompson, and Robert D. Elliott, Aerometric Research, Inc., Goleta, California, April 15, 1962.

Considering now the 50% of the pilots who will take-off into marginal weather, 20% x 50% or 10% will experience narrow escapes or will encounter weather better than forecast. The remaining 40% will encounter IFR weather conditions enroute. However, a portion of this group are expected to receive in-flight warnings through the planned national coverage of continuous operational weather broadcasts.

According to FAA statistics[1] more than three quarters (78%) of all general aviation aircraft are equipped with radio communication gear while 22% have no such equipment. Assuming that there will be no change in this ratio by 1975, approximately one quarter of the 40% or 10% flying into unfavorable weather will not receive enroute weather warnings. Most of these must be expected to have accidents. Of the remaining 30%, who have communication equipment on board, a certain portion will receive in-flight weather reports. They will thus have the choice of landing at an intermediate airport before encountering IFR weather conditions or returning to the departure terminal. This portion is conservatively assumed to comprise half of the 30% or 15%, which will be considered saved while most of the remaining 15% will have accidents.

The above estimates apply to the period 1968-69 when full implementation of those improvements, pertaining particularly to the general aviation segment, will have been accomplished. (See implementation schedule, Figure 27). If it is postulated that implementation is started during 1963, a transition period of 5 years ensues during which time there will be various stages of partial implementation.

In order to provide an indication of the reduction in fatalities for the beginning of this period, when approximately 10% of the improvements will be implemented (10 out of 100 planned pilot-to-forecaster stations, 75 out of 750 automatic telephone briefing facilities, etc.), the availability of operational weather information to general aviation pilots during this period must be examined. The

[1]FAA Statistical Handbook of Aviation, 1961

CAWS plan calls for early implementation at the larger traffic hubs where pilot population is from 2-3 times as dense as in the average hub. Thus with a 10% implementation an estimated 30% of the pilots will be reached. Half of these pilots will act on an unfavorable weather forecast and will thus be saved (15%). The remaining 15% will take-off. Of this percentage about 1/3 or 5% will experience narrow escapes or encounter VFR weather. This group will be saved. A portion of the remaining 10% will receive enroute weather warnings and avoid an accident by an intermediate landing or return to their departure terminal. This portion will be approximately 1/3 or 10% of 3%. Most of the remaining 7% are expected to have accidents.

The large group of pilots, 70%, who will not be reached by weather briefings, will encounter IFR weather conditions, enroute or at the destination terminal. Assuming again that 1/3 of these will receive enroute weather warnings through radio communication and act on them will result in an estimated 22% being saved and 47% having accidents.

Summarizing the potential reduction in accidents during unfavorable weather conditions for the two periods, 1963-64 and 1968-75, we arrive at the following breakdown.

PERIOD 1963 - 1964

Pilot Group	Accidents Prevented	Accidents
Pilots who receive operational weather briefings and act on them	15%	
Pilots who do not act on unfavorable weather briefings but have narrow escapes.	5%	
Pilots who take-off into unfavorable weather and do not receive enroute weather warnings. These are expected to have accidents.		7%
Pilots who act on enroute weather warnings are expected to be saved.	3%	
Pilots who receive no weather briefings prior to take-off and who receive no enroute weather warnings. These are expected to have accidents		48%
Pilots who receive no weather briefings prior to take-off but who act on enroute weather warnings.	22%	
TOTAL ESTIMATED 1963-64 PERIOD	45%	55%
PERIOD 1968 - 1975		
Pilots who act on weather briefings	50%	
Pilots who do not act on unfavorable weather briefings and have narrow escapes.	10%	
Pilots who do not act on unfavorable weather briefings and have no communication gear on board with which to receive enroute weather warnings. These are expected to have accidents.		10%
Pilots with communication gear on board and who receive enroute weather warnings are expected to be saved.	15%	
Pilots with communication gear who do not receive enroute weather warnings are expected to have accidents.		15%
TOTAL ESTIMATED, 1968 - 75 PERIOD	75%	25%

The maximum potential benefits which could be realized by full implementation of the planned improvements in the aviation weather service have been estimated by applying the 75% figure developed above to the total penalties associated with general aviation accidents as projected in Part I of this report. The results are presented in Table 64.

Table 64. Maximum Potential Benefit from Reduction in General Aviation Accidents (Millions of Dollars)

Item	1960	1965	1970	1975
Fatalities and Injuries	138.85	179.82	223.16	270.40
Aircraft Damaged and Destroyed	11.67	14.44	16.60	18.45
Total	150.52	194.26	239.76	288.85
Estimated Realizable Benefit (Total x 75%)	112.89	145.71	179.82	216.63

These dollar benefits are primarily based on the estimated economic losses due to an aviation fatality. These values are considered to be minimum amounts. A recent study completed in 1962 by United Research, Inc. for the FAA[1] estimates the economic loss from an aviation fatality at a much higher figure, i.e., $450,000 in 1963-64, $520,000 in the 1968-69 period and $610,000 in 1975, compared to our estimates of $271,000, $314,000 and $364,000, respectively.

[1] "Economic Criteria for Federal Aviation Agency Expenditures", Final Report June 1962, United Research, Inc., Cambridge, Mass.

b. Delays

The total penalties incurred by general aviation through delays due to weather causes were estimated in Part I. The losses are comprised of additional direct operating costs and loss of passenger time. To estimate the maximum realizable benefit, the 75% factor, developed in the preceding section, was applied to the total penalty. The results are presented in Table 65.

Table 65. Maximum Potential Benefit from Reduction of Delays in General Aviation (Millions of Dollars)

Item	1960	1965	1970	1975
Direct Operating Costs	7.12	8.74	10.25	11.46
Loss of Passenger Time	5.55	9.10	13.00	18.80
Total	12.67	17.84	23.25	30.26
Estimated Realizable Benefit (Total x 75%)	9.54	13.38	17.43	22.71

The above estimates do not take into account the fact that prior to the implementation of the improvements the benefits would in fact be zero. Only after the full improvements have been implemented will the benefits be realized at 100%. Thus, between 1963 and 1969 there is a transition period during which the expected benefits will increase from zero to their full value. Table 66 lists values of these estimated annual benefits, adjusted for the transition period.

It is not the purpose of this study to find remedies for the penalties developed here. However, the fatality figures in General Aviation and the damage to or destruction of General Aviation aircraft can no doubt be

Table 66. Adjusted Annual Benefits in General Aviation, 1963-1975 Period (in million dollars)

Year	Non Adjusted Dollar Benefits	Adjusted Dollar-Benefits
1963	149.39	1.49
1964	151.71	8.25
1965	159.09	27.10
1966	166.72	66.69
1967	174.35	104.61
1968	181.98	145.58
1969	189.63	174.46
1970	197.25	193.31
1971	205.68	205.68
1972	214.08	214.08
1973	222.54	222.54
1974	230.91	230.91
1975	239.34	239.34

greatly reduced by improved pilot training in meteorology and by better availability of more operationally oriented weather information. This opinion is supported by the fact that weather caused accidents in the case of the air carriers have been practically eliminated. Air carrier flight crews are disciplined and receive intensive training in weather. In addition, they receive detailed operational weather information which is used in planning each trip.

2. **Air Carriers**

In this section, the maximum potential benefits which could be realized through full implementation of the CAWS design have been estimated using 1960 as the base year. Actually, the improvements to the aviation weather service are expected to be initiated in 1963 and be completed by 1970. Thus the degree of implementation will rise from zero to one hundred percent during this period. These percentages must be applied to the maximum possible benefits to obtain the actual realizable benefits in each category. This latter step was done later in the report in Part III C.

a. Diversions

If an aircraft does not land at its destination terminal but proceeds to an alternate, the resulting diversion involves the penalties previously considered, such as additional flying time, lost passenger time, interrupted trip expense and usually a ferry trip of the empty aircraft to the original destination terminal. If the aircraft, after a diversion, does not reach its destination terminal in time for the next scheduled departure, the carrier will be obligated to provide extra equipment or lose the revenue from this trip.

Diversions occur in all airspace user categories: General Aviation, Air Carriers and Military Aviation. However, only the diversions suffered by the scheduled carriers will be treated here, since for this category suitable statistics are available and can be projected over the 15 year period ahead.

The causes of diversions are two-fold:

Terminal weather conditions are found to be below landing minimums by the approaching aircraft, as the result of an incorrect terminal weather forecast, or

- Long waiting periods in a terminal holding pattern, usually the result of scheduling congestion during marginal weather periods, force the aircraft to proceed to its alternate after the reserve fuel has been used up in the "stack".

Both of these causes are essentially due to the uncertainty of forecasting terminal conditions. Turbojet aircraft, in particular, are heavily penalized when placed in a holding pattern at low altitudes because of their extremely high fuel consumption at these levels. The decision to divert must be made before the descent is started.

The type of forecast most applicable to diversions is the 9-12 hour terminal forecast. Flight planning for the average flight is usually accomplished 1-2 hours prior to take-off. Flight planning includes providing for adequate fuel reserves for diversions. The terminal forecast available at the time of flight planning may be from 1-5 hours old. Finally, the usual length of flight where diversions are a distinct possibility, extends over medium to large distances involving a period of 3-5 hours.

The benefits to be derived from a reduction in diversions can be considered directly proportional to an improvement in forecasting accuracy of terminal weather, primarily of the type involving below minimum landing conditions.

An analysis of current forecasting accuracy of terminal weather using the results of a verification study by Aerometric Research[1], which was carried out over a 3 year period, shows that of a total of 91670 terminal forecasts at 21 nationally distributed airports, the weather was observed

[1] "Quantitative Assessment of the Performance Characteristics of the Airways Terminal Forecasting System", Aerometric Research, Inc. Goleta, California, April 15, 1962, U. S. Weather Bureau, Contract Cwb 10077

to be below landing minimums 947 times, or approximately 1% of the time, that above minimum conditions were forecast. While this accuracy is relatively high, the implementation of the Common Aviation Weather System is expected to improve the forecasting accuracy of terminal weather conditions by an estimated 50% thus reducing the degree of inaccuracy from 1% to 1/2%.

Table 67 projects the estimated benefits from reduction of diversions through the period 1960 to 1975, assuming the improvements had been implemented prior to 1960. Since an eliminated diversion leads to an additional cancellation, the cost per cancellation has been subtracted from the diversion cost. Thus, only the net cost per eliminated diversion is used here in the determination of the benefits.

Partial Table 67. Dollar Benefits due to Reduction of Diversions

Item	1960	1965	1970	1975
Estimated number of Diversions Eliminated[1] (50% of Total)	3250	3900	4550	5250
Cost per diversion[1]	\$703	\$916	\$1044	\$1076
Cost per cancellation[2]	\$122	\$116	\$179	\$244
Net Gain Per Eliminated Diversion	\$581	\$800	\$865	\$832
Total Estimated Dollar Benefit Due to Eliminated Diversions (millions)	\$1.89	\$3.12	\$3.94	\$4.37

[1] See Section 7, Part 1 A

[2] See Section 6, Part 1 A

b. Cancellations

As discussed in Section 6, Part IA, cancellations are due to two principal causes, weather factors and mechanical failures. Assuming that weather was not a factor during the summer months, the increased amount of cancellations during the rest of the year was then ascribed to weather causes, yielding an annual average of 1.19% of all scheduled aircraft mileage cancelled.

In these cases, the flights were cancelled due to a forecast of weather below minimums at the terminal, and nearby alternates, at the scheduled arrival time of the aircraft. A terminal weather forecast study[1] has shown that, for a three year period, 1958-1960, below minimum forecasts for a 12 hour period verified 24.7% of the time. Stated another way, below minimum weather was forecast four times for every once that it actually occurred. If it is assumed that all flights were cancelled on the basis of these forecasts, this means that three out of every four cancellations were unnecessary. This appears to be an over-statement of the case since in a certain portion of these cases, a suitable alternate may be available.

Accordingly, it will be assumed that one of these three cases was not cancelled and the flight was conducted in spite of the unfavorable forecast. This results in an estimate that two out of every three cancellations are unnecessary. Following the same line of reasoning as in the case of diversions[2], it is estimated that implementation of the Common Aviation Weather System will improve this type of forecast by 50%. This will then eliminate one of the two unnecessary cancellations and reduce the total amount of cancelled flights by one-third.

Table 68 projects the estimated maximum possible benefits resulting from the reduction in cancellations, assuming the improvements to have been implemented in 1960.

---

[1] Cited pg. 250

[2] Pg. 251

Table 68. Maximum Possible Benefits Due to Reduction in Cancellations

Item	1960	1965	1970	1975
Total Number of Cancellations	45,400	54,400	63,700	73,700
Net Cost (millions)	5.54	6.34	11.37	18.00
Maximum possible benefit (1/3) (millions)	1.85	2.11	3.79	6.00

In practice, general aviation and the military undergo penalties due to unnecessary flight cancellations. However, an actual dollar estimate of the penalties has not been attempted since it would be highly speculative due to lack of suitable data.

c. Delays

(1) Air Carrier Delays, Enroute

In arriving at any potential benefits to be expected from the proposed augmentation of the present weather services affecting enroute air carrier performance, several possibilities present themselves.

Accurate flight planning, notably for the turbojets, is an economic necessity and becomes increasingly important with the expected increase in turbojet flying. The general planning of an air carrier flight with the weather information input as well as the possible results of inaccurate flight planning are shown in the following table. All these items are subject to improvement.

Weather Parameter	Potential Effect of Inadequate Flight Planning	
	Turbojet	Propeller
Accuracy and Timeliness of Upper Air Wind Forecasts (including minimum time track)	1. Fuel load excessive a. Increased fuel consumption b. Off loading payload c. Restricted take-off performance 2. Fuel load inadequate a. Unscheduled fuel stop b. Necessity for increased altitude or reduced thrust for fuel conservation	1. Little effect on short range flights but important on longer range flights. 2. Altitude selection important to total flight time.
Accuracy of Temperatures Aloft Forecasts	1. Little effect on fuel consumption at cruise altitude 2. Temperature determines cruise altitude restricted by gross weight 3. Can increase trip flying time due to aircraft performance at excessive cruising altitude. 4. Can increase fuel consumption by selection of too low cruising altitude	1. Little effect
Accuracy of surface temperature forecasts	1. Determines take-off weights which in turn can determine choice of alternates, choice of altitude for fuel economy, choice of min. flight time configuration. 2. Can effect available payload	1. Can effect available payload

Weather Parameter	Potential Effect of Inadequate Flight Planning	
	Turbojet	Propeller
Accuracy of surface temperature forecasts (cont'd.)	3. Must be available several hours prior to departure for load planning purposes.	2. Must be available several hours prior to departure for load planning purposes.
Route Choice (unfavorable weather, turbulent or thunderstorm areas)	1. Can result in increased flying time due to decreased airspeed through turbulence or thunderstorm areas. 2. Increased fuel consumption due to changing airspeeds. 3. Can result in unnecessary passenger discomfort as well as injury or aircraft damage.	1. Can result in increased flying time due to decreased airspeed through turbulence or thunderstorm areas. 2. Can result in unnecessary passenger discomfort or injury as well as aircraft damage.

From the above table, it can be surmised that a correctly planned flight can result in maximum speed, passenger comfort, minimum flight time, and minimum operating cost. Some of these factors are measureable, others are not.

Presently air carrier turbojet flights are planned either by electronic computers or manually from charts and tables designed for ease and speed of calculation. With both, hand tables or the electronic computer, certain information is fed into the machine or applied to the tables to arrive at the flight plan. This information will include the performance data of the aircraft concerned, planned payload and weight at time of take-off, route mileage, temperatures aloft and upper air wind forecast data for the flight. The use of weather information is decisive in the final accuracy of the flight plan.

Present indications are that the forecast methods now used are reasonably satisfactory based on the reliability of the input data. If the weather inputs are accurate, the flight planning is usually accurate, and no improvements can be expected in this phase.

The timing and frequency of upper air observations, however, represent an area of potential improvement. Presently wind forecasts are many hours old before they are received and processed into a flight plan. The time of day at which these soundings are made is also an important factor in considering benefits to be realized from this source.

Presently the upper air soundings are taken at 12 hour intervals at 00:00Z and 12:00Z (Greenwich time) respectively. However, it is shown elsewhere in the report that 80% of the aviation activity takes place between 14:00 and 04:00 Z. The flow of upper air data from observation to forecast to flight plan time is as follows:

Observations taken	00:00Z
Observations received by forecaster	02:15Z
Processing and Forecast	06:15Z
Users Receive Forecast	07:15Z
Start of Flight Activity	14:00Z

This results in a minimum delay of 14:00 hours up to a maximum of 26 hours between the observations and the actual flight using the information.

Improvements as incorporated in the CAWS implementation plan stipulate four observations per day instead of the present two. This will reduce the time lag and result in more timely inputs to the flight planning activities, thus increasing the accuracy of flight plans. The other main activity which would benefit from this increased accuracy of upper-air information is the ATC system. This will be especially pertinent when the weather support stations to the traffic control centers, which are a part of the planned improvements, are implemented.

Variation in schedule performance determines the amount of slack built into any published schedule. Conversely, the relative tightness of the schedule determines the amount of "paper" delays incurred from each cause. If schedules are loosened to the extreme, practically all delays will be eliminated. However, the high cost of such schedule expanding as shown elsewhere in the report prohibits such unrestrained manipulation of the published schedule. Usually a compromise is made between actual on-time performance and the published schedule time.

The variability of performance in air carrier operations induced by weather factors is indicated by the chart in Figure 29. It can be seen that the overs and unders caused by the indicated weather factors will produce the present level of on-time performance when combined with all other factors which also influence performance, such as traffic congestion, local weather, field conditions.

A reduction of any individual factor will produce a new set of on-time arrivals which can be resolved into a better performance or on time situation; also such reduction can result in a tighter schedule and still retain the present on time arrival percentages.

From the experiences of carrier meteorological personnel engaged in the operation of flight plan computers, it is found that inaccurate weather information inputs at present result in about 20% "misses" in flight plan computations. These "misses", which may amount to as much as 15 minutes for a transcontinental flight, result in a less favorable on time performance. Estimates by the same personnel indicate that half of these misses could have been eliminated had more timely weather information been available.

Other qualified sources indicate that under ideal conditions with perfect weather information available, 75% of the enroute delays could be

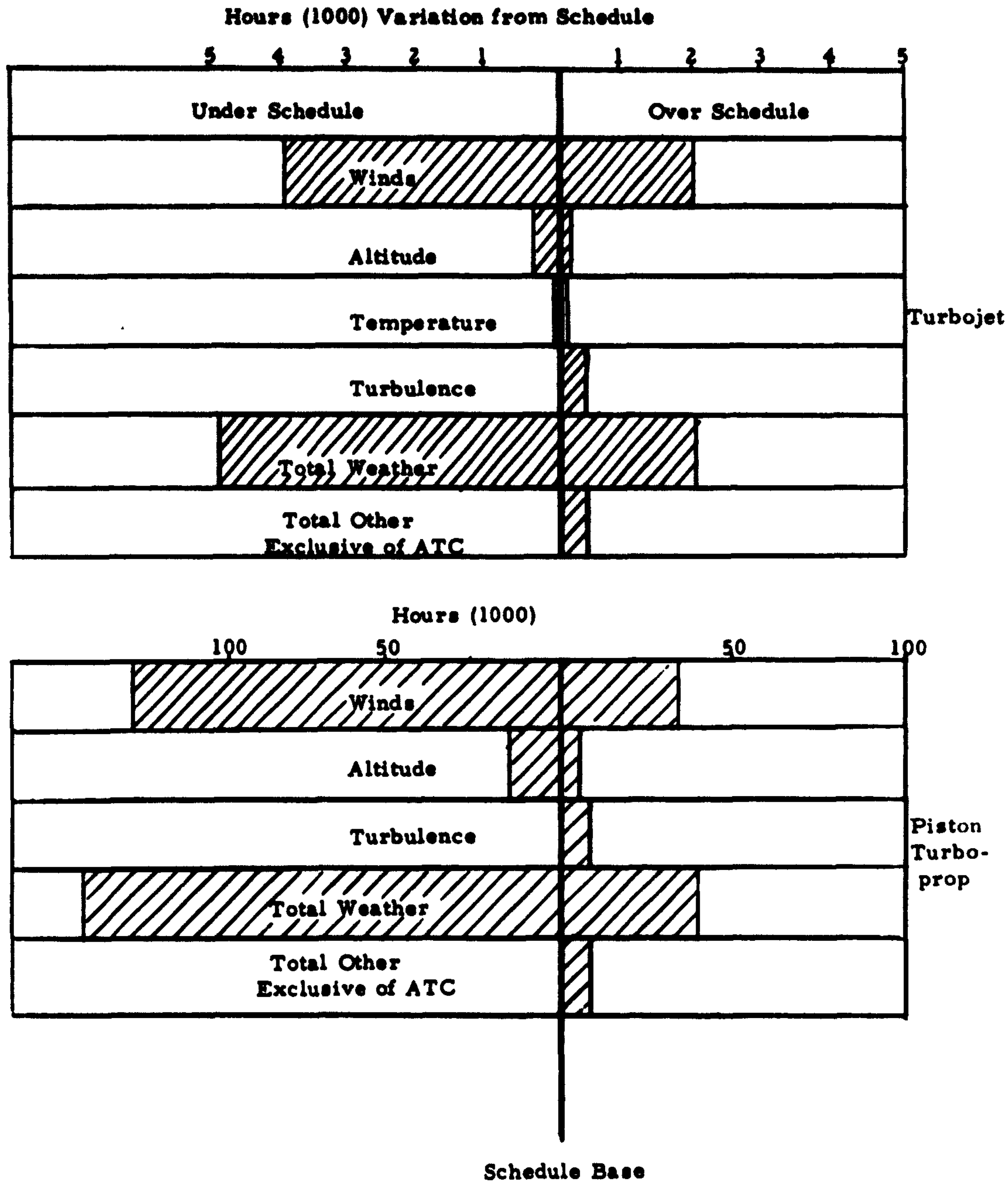

Figure 29. Hours (1000) Variation from Schedule

eliminated by proper choice of altitude and route, consideration being given to winds, temperatures, and turbulent areas. With the expected improvements in forecast accuracy it is estimated that 10% of the total penalties could therefore be eliminated and could be considered as a benefit.

Propeller flights have approximately the same wind information available, which is usually obtained from the originating dispatch offices. The degree of error and the increase in accuracy to be expected would be of the same magnitude as in the case of the turbojets. Upper air temperature forecasts would have little effect on the propeller driven aircraft. The table below shows the total projected penalties and estimated benefits from reduction in air carrier weather delays.

Table 69. Projected Benefits Due to Reduction in Air Carrier In-Flight Delays (Million dollars)

Item	1960	1965	1970	1975
In-flight Delays, Direct Operating Costs	$8.70	$15.30	$23.10	$30.10
Passenger Time Lost	$19.90	$29.25	$45.50	$65.25
Total In-Flight Weather				
Penalties	$28.60	$44.55	$68.60	$95.35
Benefits (10%)	$2.86	$4.45	$6.86	$9.54

(2) Air Carrier Delays, Maintenance

The benefits to be derived from a reduction in maintenance delays are primarily a function of improved forecasting.

As a result of discussions with maintenance management personnel of three major trunk carriers, it has been estimated that a 10% reduction in maintenance delays as a result of the planned improvements would be a conservative figure. This percentage is probably higher when the twenty odd carriers are considered, which do not have their own meteorological departments and depend solely on the more generalized aviation weather information prepared by the U. S. Weather Bureau.

With the 10% estimated reduction, the expected benefits in maintenance delays are presented in Table 70.

Table 70. Estimated Maximum Possible Benefits Due to Reduction in Maintenance Delays (million dollars)

Item	1960	1965	1970	1975
Total Maintenance Penalty	$8.73	$11.26	$13.05	$14.20
Estimated Benefit (10%)	$ .87	$1.13	$1.30	$1.42

d. Alternate, Contingency and Pilot's Contingency Fuel

(1) General

The greater portion of the contingency and alternate fuel carried is directly proportional to the lack of confidence of the operating personnel in the forecasting of weather parameters affecting the flight. Secondary considerations are air traffic control, field conditions at the destination, variable aircraft engine performance and other unpredictable factors.

The length of the flight and the type of weather to be expected influence the pilot's decision on alternate selection. On a longer flight he is more apt to name an alternate even though the weather may be well above minimums. Also the proximity of the forecast weather at the destination terminal to the conditions actually requiring an alternate will influence the pilot's decision to name an alternate.

Specific weather parameters which may lead to a request for additional fuel load reserve are winds aloft and temperatures at cruising altitudes. A well calculated flight plan can turn out to be inaccurate when the route lies close to jet streams, strong pressure ridges, troughs, and strong winds in general. In such cases a slight shift of these features during the forecast period can produce large effects with respect to head and tail wind components.

These uncertainties call for an extra fuel pad which is fully justifiable in the present state of the art. A "miss" on a flight plan which calls for strong tailwinds must be covered by a jet either by climbing to higher altitudes for fuel conservation or by carrying an additional fuel pad. Thunderstorm activity also adds uncertainty and may require a detour or reduced speed.

The selection of a relatively high cruising altitude for the flight plan may also require additional reserve fuel. Should this altitude be unavailable because of ATC conflicts or for other reasons, the fuel consumption would exceed that planned, making a reserve necessary.

In addition to those alternate terminals specified on the basis of pure weather requirements, an alternate must be named in the event of certain terminal runway conditions, such as single runway, icy or slippery runways, etc. Some 20% of the total turbojet flights required such an alternate[1] in addition to the alternates required for weather reasons only. This amount is not included in the total weather alternate fuel penalty.

---

[1] United Air Lines data September, 1961, LAX Departures, (1500 flights) 20% named single runway alternates. This segment is exclusive of weather alternates.

The factors affecting alternate and contingency fuel requirements are listed in the table below:

Alternate Fuel	Standard Contingency Fuel	Pilot Contingency Fuel
*Terminal weather vs. landing minimums	*Variance in enroute temperatures	*Confidence in forecast
*Potential thunderstorms in terminal areas	*Variance in enroute winds aloft	Length of flight
Single runway at terminal	Engine performance	*Imminent adverse weather near time of arrival
	ATC requirements	
*General type of weather in terminal area	*Enroute thunderstorms	Experience with aircraft type
	Flight plan based on high altitude	Flight plan based on high altitude
	*Flight plan based on strong tailwinds	*Flight plan based on strong tailwinds
	*Presence of jet streams, pressure, troughs, ridges enroute.	

*Weather factors considered for this report

(2) Alternate Fuel Requirements

Terminal weather forecasting and its accuracy play an important part in the total reserve fuel costs. Forecasts of probable thunderstorms and the possibility of marginal ceiling and visibility in the terminal area are the primary weather reasons for carrying alternate fuel.

- **Thunderstorms**

  The availability of complete ground weather radar at the terminal, coupled with the airborne observing equipment would virtually eliminate the need to carry alternate fuel due to the possibility of thunderstorms in the vicinity of the destination terminal. Of all flights requiring the naming of an alternate only 1/2% specify terminal thunderstorms as the weather factor. Thus, the effect of better thunderstorm information in reducing the carriage of alternate fuel has been treated as negligible.

- Ceiling, Visibility

  Terminal weather, primarily ceiling and visibility, is the most important weather factor, affecting the naming of an alternate for the IFR flights. In the reserve fuel penalty analysis[1] it was found from the conservative Chicago sample that 56% of the total propeller aircraft and 62% of the turbojets carried alternate fuel. The weighted total, combining turbojet flights and propeller aircraft flights, was computed at 57% for 1960. Actually the shift will be towards jet aircraft in the 15 year period ahead which will put the percentage closer to the 62% mark.

  In order to arrive at the percentage of IFR flights where alternate fuel was actually required and where alternate fuel was carried unnecessarily in the light of subsequent weath·r verification, the results of a recent forecast

[1] See page 41.

verification study[1] have been employed. The study uses all the hourly terminal weather observations from 21 major terminals for the calendar years 1958, 1959, and 1960.

Forecasts were checked for the 0, 3, 6, and 12th hour of the forecast period when at sometime during the forecast period a ceiling of 1500 feet and a visibility of 5 miles or less was observed.

Table 71. Description of Forecast Categories

Category	Condition	Visibility (mi)	Ceiling (ft)
I	Below minimums	$V < 1/2$	$cig < 200$
II	Low IFR	$1/2 \leq V < 1$	$200 \leq cig < 500$
III	High IFR	$1 \leq V < 3$	$500 \leq cig < 1000$
IV	Low VFR	$3 \leq V < 5$	$1000 \leq cig < 1500$

The average percentages of correct forecasts, or "hits" where the actually encountered terminal weather corresponded to the forecast within the limits specified in the table above for 21 nationwide stations, were as follows:

	Average Percent Correct
0 hour	49.4
3rd hour	31.1
6th hour	24.2
12th hour	19.0

From these average percentages of correct forecasts it can be seen that the 6 hour forecasts were found to be correct only 24.2% of the time and the 12

[1]Kerr, R. E., Jr., Thompson, J. R., and Elliott, R. D.: "Quantitative Assessment of the Performance Characteristics of the Airways Terminal Forecasting System" Aerometric Research, Inc., April 15, 1962

hour forecasts only 19% of the time. Thus, the decisions as to the carrying of alternate fuel, which are primarily made from 6-12 hour forecasts, are based on inputs which have been shown to be incorrect at least 75% of the time or three times out of four. The effect of this uncertainty has led the carriers to build many expensive operational "hedges" into their flights. It has also led to the Federal rule that alternate fuel is required when two hours prior to and two hours after the estimated time of arrival at the destination terminal, the ceiling is forecast to be less than minimum approach altitude plus 1000 feet. This legal "pad" of 1000 feet above minimum approach altitude leads to an average minimum ceiling at the 21 national airports sampled of 2400 feet. If ceilings are forecast to be below this value at ±2 hours from estimated time of arrival, alternate fuel is legally required.

In cases where, according to a terminal forecast embracing Categories I to IV, alternate fuel was required to be carried, investigation reveals that 66% of the arrivals were under conditions where alternate fuel was not actually needed. It will be noted that Categories I to IV include only ceilings of 1500 feet or less. Had these categories been extended to the average legal ceiling minimum of 2400 feet, at least 80% of the flights need not have carried alternate fuel.

The map in Figure 30 shows the locations of 18 of the stations from which the samplings were made. In the bar graphs the left bar indicates the number of time when alternate fuel was required according to the forecast and the right bar the number of times when alternate fuel was actually required on the basis of observed weather at arrival time.

While the sampling is quite representative as to area, the terminal forecasts were averaged on an annual basis which does not take into account diurnal variations of traffic. However, over 60% of all air traffic takes place during the daylight hours from 8 a.m. to 8 p.m. For arrivals during this period, the study finds that the forecast accuracy is somewhat less than during the entire 24 hour period, which renders the sampling more conservative.

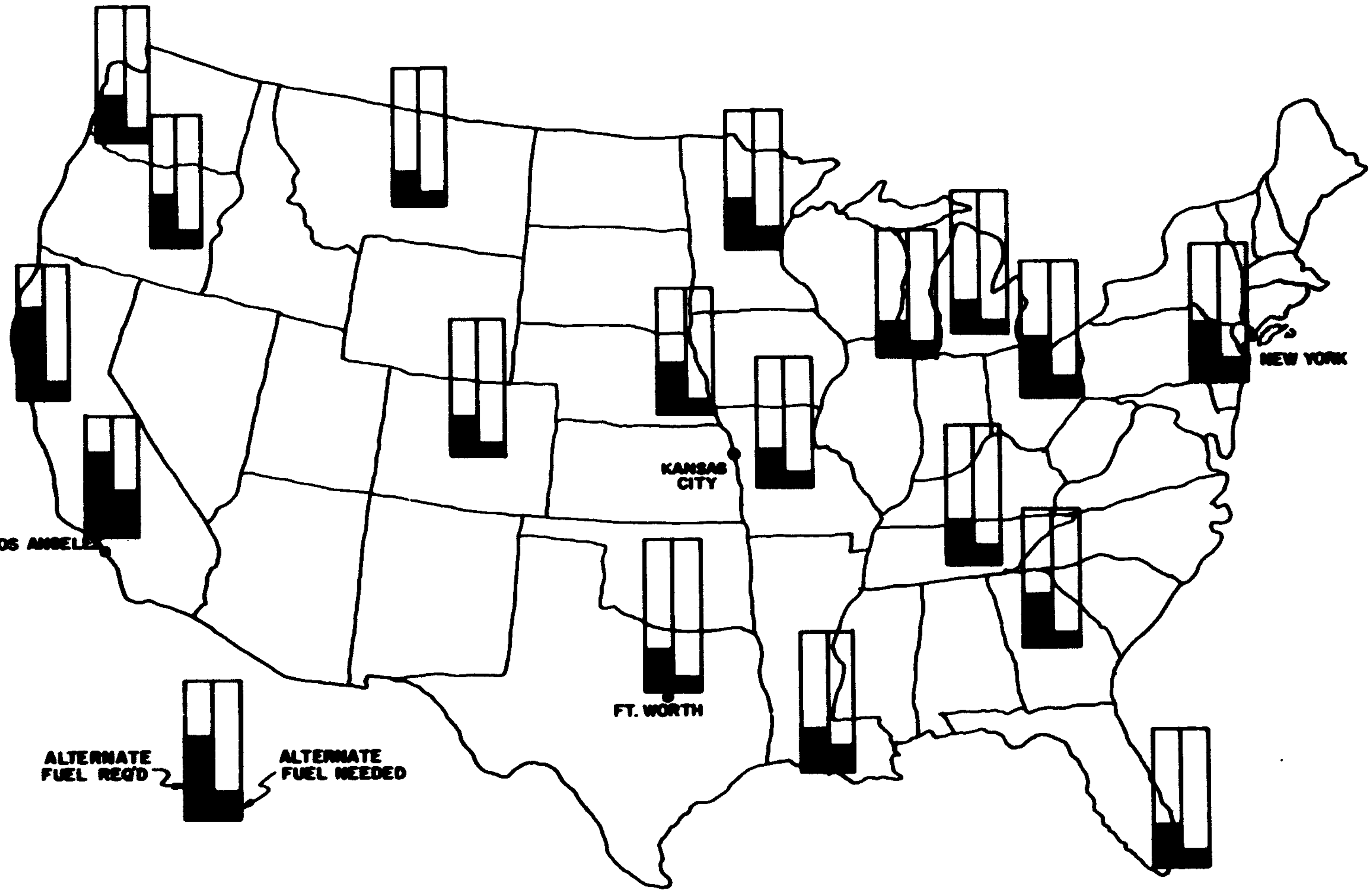

FIGURE 30. ALTERNATE FUEL REQUIRED ACCORDING TO TERMINAL FORECAST VS. ALTERNATE FUEL ACTUALLY REQUIRED ACCORDING TO FORECAST VERIFICATION

The actual benefits to be realised from a reduction in alternate fuel carried will result from one or both of the following:

- Without altering the legal "pad" of 1000 feet above landing minimums, the accuracy of forecasting below 2400 feet ceiling conditions can be improved.
- As a result of the planned improvements in the national aviation weather services, the 1000 foot "pad" will be appreciably reduced or even eliminated.

Improvement in accuracy of forecasting ceiling conditions below 2400 feet is not likely to lead to any reduction in alternate fuel. Discussions with operations personnel of several major air carriers revealed that generally an extremely high credibility will have to be achieved for forecasts of marginal terminal conditions before any appreciable reduction in the designation of alternate terminals will take place. This will required forecasting accuracies in the neighborhood of 95%, which are not likely to be reached in the next few years. Thus for this first case we will assume a potential reduction in alternate fuel penalties of 5%.

The second possibility, involving the reduction or elimination of the altitude "pad", will result in an elimination of 80% of the present alternate fuel penalty. These two cases lead to two potential benefit limits, a lower limit of 5% of the penalty and an upper limit of 80% of the penalty. Table 72 below shows the projected dollar values of these benefits for the period 1960-1975.

Table 72. Potential Benefits from Reduction in Alternate Fuel Penalty (million dollars)

Item	1960	1965	1970	1975
Total Alternate Fuel Penalty	$4.90	$20.40	$37.00	$54.00
Lower Limit Benefit (5% Reduction)	.24	1.02	1.85	2.70
Upper Limit Benefit (80% Reduction)	3.92	16.32	29.60	43.20

(3) Contingency Fuel Benefits

This reserve pad as previously discussed is a blanket amount of fuel carried on each flight for numerous unforeseen eventualities, usually a minimum of 4000 lbs. Weather accounts for the majority of these possibilities. However, this reserve probably will never be completely eliminat ed. Experienced planners estimate that 25% of this fuel pad can eventually be eliminated with increased confidence on the part of the pilots and dispatchers in terminal and enroute weather forecasts, as well as increased operating experience with the flight equipment.

Table 73. Potential Benefits from Reduction in Contingency Fuel (Million Dollars)

Item	1960	1965	1970	1975
Total Contingency Fuel Penalty	$1.80	$15.00	$28.70	$42.70
Contingency Fuel Benefits	0.45	3.75	7.17	10.67

(a) Pilot Requested Contingency Fuel

This reserve fuel requested by the pilot of the flight can readily be eliminated by increased accuracy of forecasting, better observations, and primarily by faster communications (i.e., pilot-forecaster). These costs are therefore considered as potential benefits in their entirety.

Table 74. Potential Benefits from Reduction in Pilot Requested Contingency Fuel Penalty

Item	1960	1965	1970	1975
Pilot Requested Contingency Fuel in Millions of Dollars	$0.41	$3.40	$6.49	$9.52

In summing up the total estimated benefits to be derived from a reduction in the reserve fuel penalties, the lower and upper limits are listed here for the period 1960-1975.

Table 75. Total Estimated Benefits from Reduction in Alternate and Contingency Fuel (million dollars)

Item	1960	1965	1970	1975
Alternate Lower Value	$ .24	$1.02	$1.85	$2.70
Upper Value	3.92	16.32	29.60	43.20
Contingency Fuel Benefit	.45	3.75	7.17	10.67
Pilot's Contingency Fuel Benefit	.41	3.40	6.49	9.52
TOTAL BENEFIT LOWER VALUE	1.10	8.17	15.51	22.89
TOTAL BENEFIT UPPER VALUE	4.78	23.47	43.26	63.39

Table 76. Summary of Maximum Potential Benefits, Air Carriers

Item	1960	1965	1970	1975
Diversions	1.89	3.12	3.94	4.37
Cancellations	1.85	2.11	3.79	6.00
Delays	2.86	4.45	6.86	9.54
Maintenance	0.87	1.13	1.30	1.42
Alternate and Contingency Fuel	1.10	8.17	15.51	22.89
Totals	8.57	18.98	31.40	44.22

3. ATC System and User Delays

a. General Considerations

Potential benefits to be expected from a more complete utilization of weather services by the ATC system can be estimated from the weather-induced penalties previously calculated. It should be noted that, for the most part, these penalties are not necessarily imposed on the system or the users because of the weather itself but rather because of the fact that weather information is not presently incorporated into the operation of the ATC system.

A previous part of this study examined the total ATC delays imposed upon the users of the system and the economic penalty suffered because of these delays. The delays include such non-weather parameters as traffic congestion induced by trip scheduling, airway congestion, availability of airway altitudes and routes, navigational aids, restricted areas, capacity of terminal areas for receiving inbound aircraft or for releasing departing aircraft.

ATC weather delays by definition will include any changes of routings or altitudes because of wind conditions aloft, turbulence, presence of thunderstorms, reduced airspeed or ground-speed because of weather factors, reduction of available altitudes because of the presence of icing layers, missed estimates and added updatings because of unexpected winds aloft conditions, missed approaches because of unforeseen adverse weather conditions in the approach areas, terminal conditions affected by weather, as well as diversions to alternate terminals.

The weather effects on the system and on the users of the system are analyzed separately for each activity to determine the potential benefits possible from incorporating weather services into the ATC system and from the utilization of such weather information both by the present control system and by the ATC system planned for the future.

b. ATC System

At present the use of weather information and weather services in the ATC system is limited. Only two centers, Washington, D. C. and Kansas City, Mo. are supplied with weather support by the experimental pilot-to-forecaster services. These represent a move toward introducing more weather information into the ATC system.

A list of the penalties suffered by the ATC system due to non-use of weather information is given below:

- Increased workload due to flight plan changes caused by adverse weather conditions, or lack of knowledge of current weather conditions.
- Increased personnel requirements due to peak workloads induced by critical weather situations.
- Decreased efficiency of the traffic control system due to increased workload or the inability of the system to perform its assigned mission to the optimum extent.
- Increased possibility of errors, thereby decreasing the reliability and capacity of the ATC system.
- Missed approaches due to inaccurate weather observations and forecasts resulting in an increased controller workload.
- Standard routings are presently used without consideration of weather information until the flights involved encounter unforeseen weather conditions and changes of flight plans are requested by pilots. This situation results in additional workload for the controllers.

- Due to inadequate knowledge of terminal weather, flight plans of diversions to alternate terminals must be processed after the diversion is initiated, which results in peak workloads for the controller.
- Squall lines, thunderstorm activity, turbulence, and icing layers can all produce requests for flight plan changes with a resulting increase in workload.
- For final approaches and landings, or take-offs and departures, lack of weather knowledge can induce additional workload and decrease the capacity of the ATC system to accomodate the traffic. Critical weather parameters include conditions in the approach areas, scud on the field, patchy ground fog, unusual wind conditions, turbulence, wind shears, direction and velocity of surface winds, effect of jet or prop wash on landing aircraft, blowing dust, and others.
- Field conditions such as icy or wet runways result in slow-down of traffic acceptance. Advance knowledge of these conditions will facilitate planning, thereby reducing the controller's workload.
- Lack of radar information on thunderstorm activity leads to inefficient routing of departing and arriving traffic thus imposing an added burden on the controller's workload.

That these penalties, caused by lack of use of weather information, are real and occur frequently within the air traffic control system, is attested to by numerous actual examples. One typical case may be cited where

a line squall lay across a heavy traffic route very close to the general point of start of descent. The line was not forecast nor was its location known or forwarded to the flights entering the area. Each flight approaching the area had to request a change of flight plan involving an extensive detour in the vicinity of the terminal area where there were also numerous departures as well as arrivals. Each of the eight air carrier flights involved during this period made the request and was processed individually and rerouted. Had the location of this squall line been known and the information utilized, the rerouting could have been routine, planned well ahead, flying time would have been saved and the workload of the controllers considerably reduced.

A similar example involved an ATC Center centrally located with heavy jet "over" traffic. A thunderstorm situation developed rather rapidly involving about 1860 miles of high altitude jet airways within this center. Although the activity was forecast, it became more extensive than expected and spread rapidly across three major east-west jet airways. The increased thunderstorm activity required extensive reroutings and altitude changes. For a period of 30 minutes there were at least eleven civil jets involved, most of which required some flight plan changes. The communications and control system bogged down during this period because of the increased demands on the system. One jet was forced to reverse course, another required to accept a low altitude, thereby encroaching upon his fuel reserves, and another jet was unable to proceed past a radio fix for at least 15 minutes. The average delay for all but the very high flights was 10 minutes. Had the radar weather depiction facilities been incorporated into the ATC system and the information used in this case, all but two of the affected flights could have been rerouted in advance, since they were relatively long range flights where detours would not have affected the flying times appreciably.

Another example is the presence of icing layers in clouds. Without knowledge of the cloud tops in such cases, it is not uncommon for the controller to assign a number of trips to altitudes just short of the tops in the

areas, thereby exposing the aircraft to icing conditions. This generates additional requests for altitude changes and increases the controller's workload.

It was found that 6%[1] of all the present postings which make up the controller's workload are duplications caused by such weather situations. With adequate weather support, this manpower can be directed towards the control of new aircraft in the control zone and the duplication eliminated. This constitutes a direct gain which can be translated into a dollar figure. From a study conducted by the Franklin Institute on ATC Activities[2] the estimated cost of traffic control functions and clearance processing for the year 1960 was $118,678,000. Applying the above percentage to this total expenditure results in a $7,100,000 benefit, realized in the form of more efficient operation of the ATC system.

A projection of this value to the 15 year period ahead, based on the number of IFR hours, is presented in Table 77.

Table 77. Projected Dollar Benefits to the ATC System Itself

Item	1960	1965	1970	1975
Number of IFR Flights[3] (1000)	3,687	4,532	5,788	7,332
Average time per Flight in Hours[3]	1.25	1.13	1.03	.99
IFR Hours (1000)	4,600	5,130	5,970	7,288
Benefits to ATC	$7.10	$7.95	$9.20	$11.20

[1] See pg. 147

[2] "Flight Strip Update Investigation", The Franklin Institute, Philadelphia, Pa. 1959

[3] Ref: Forecast of Annual Flight Activity in CONUS, 1960-1975 FAA, Sept. 1961

c. **Users of the ATC System**

The lack of weather information available to the ATC system imposes specific penalties on the users of the system; the general aviation fleet, the air carriers and military aviation. These penalties are primarily composed of delays, the main causes of which are listed below:

- Weather detours because of thunderstorm activity, turbulence, icing can result in added flying time if not pre-planned.
- Flying times during departure or arrival times can be increased if an ATC selected routing is blocked by weather conditions.
- Instrument landings can result in missed approaches when adverse cross winds or turbulence are encountered in the approach area. These result in added flying time and possibly unnecessary diversions to alternate terminals.
- Radar vectoring on the part of ATC becomes relatively more inaccurate under adverse wind conditions. This results in unsatisfactory approaches.
- Approach and departure control personnel not equipped with weather radar will often direct aircraft into adverse weather conditions causing passenger discomfort, leading to added flying time and possible damage to the aircraft.
- Lack of information on the surface conditions of runways can decrease the acceptance rate of the terminal.

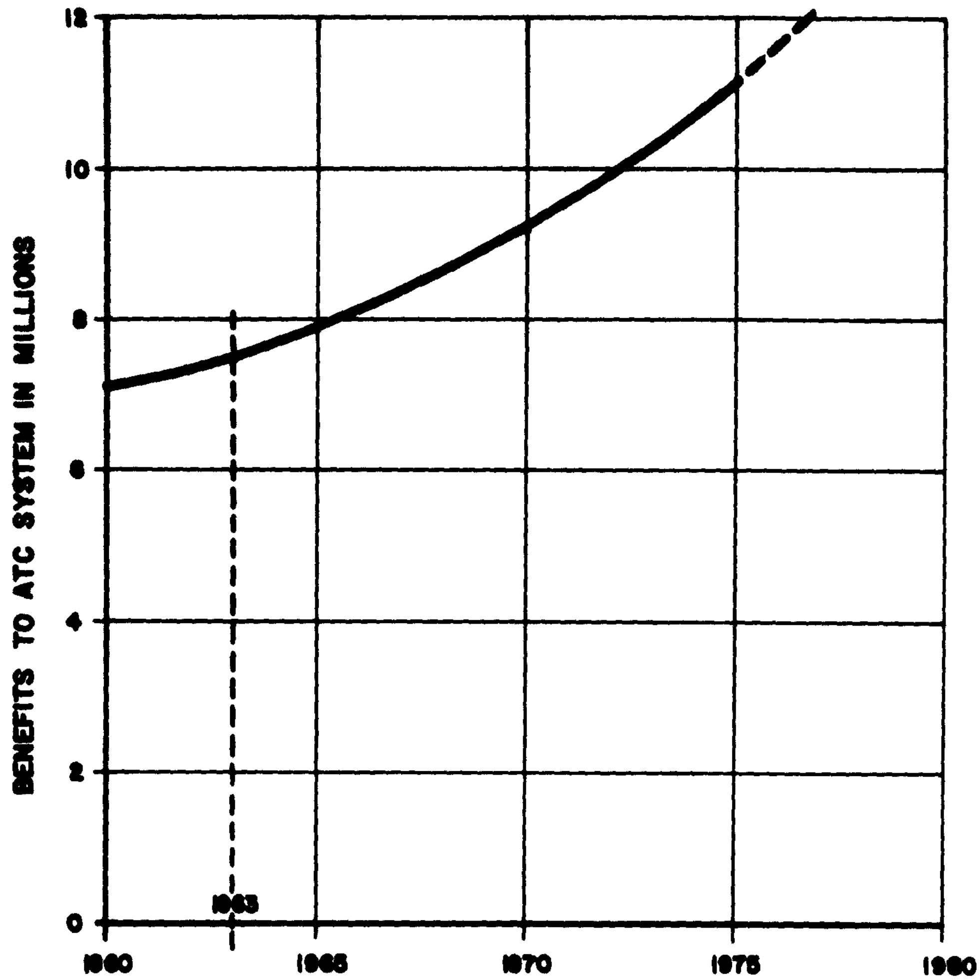

FIGURE 31. GRAPH OF PROJECTED DOLLAR BENEFITS TO THE ATC SYSTEM

The parameters/phenomena associated with these delays were examined by experienced aviation meteorologists and operations personnel and estimated to be, in order of importance:

a. Visibility/Ceiling (including low scud)

b. Thunderstorms (squalls)

c. Cloud tops and bases

d. Wind, surface and approach zone

e. Turbulence

f. Layers of Icing (including freezing rain)

Visibility/Ceiling was considered of major importance because of its effect on acceptance rate and also because of traffic flow disruptions connected with missed approaches and diversions. Thunderstorms, cloud bases and tops, and wind were also listed as of major importance. Turbulence and icing layers were considered to be of relatively minor importance. The major and minor labels result from an unwillingness to put a specific percentage of total effect on each item. Such values would be too subjective whereas classification in two categories can be made with considerable assurance.

Each item was then examined in an attempt to determine whether improvements in information would reduce or eliminate air traffic delays:

a. Visibility/ceiling - Improved observations and forecasts will enable the controller to plan ahead and thus reduce some delays. However, the majority of the delays occur under marginal conditions when the natural rapid variations in ceiling and visibility may cause them to fluctuate above and below minimums. Even if these fluctuations could be forecast, the ceiling and the reduced visibility still exist and will cause delays.

b. **Thunderstorms** - Thunderstorms are discrete phenomena which can be avoided, given foreknowledge of their location, extent and movement. Increased use of weather radar and improved communications should result in a major reduction in delays due to this cause.

c. **Cloud tops and bases** - The increased numbers and more rapid availability of pilot reports which will result from implementation of the pilot-to-forecaster system should produce a major reduction in delays in this category.

d. **Wind, surface and approach zone** - Improved short-range terminal forecasts will enable the controller to plan ahead and arrange his traffic in such a manner as to reduce the effect of surface wind shifts. Information on strong cross-winds and wind shears in the approach zone from inbound pilots, communicated to the succeeding aircraft should reduce delays due to this cause.

e. **Turbulence** - Again, introduction of the pilot-to-forecaster system should produce better and more timely information on turbulence and a reduction in delays.

f. **Icing layers and freezing rain** - Increased availability of pilot reports will result in improved information as to these weather hazards. However, these are wide-spread phenomena and little reduction in traffic delays in this category is anticipated.

Taking into account the importance, frequency and possibility of improvement in each of these six categories, a considered judgment was reached that at least 50% of the weather delays could be eliminated by the planned improvements in the aviation weather system. This amounts to 5% of the total ATC delay.

Table 78 presents the total delay penalty incurred by the three users of the ATC system, projected through 1975, and the potential benefits to be realized. The lower values are based on estimates in this report while the higher values constitute estimates from United Research, Inc.

Table 78. Estimated Maximum Potential Benefits Through Reduction in ATC System and User Penalties due to Weather Causes (Million Dollars)

Item		1960	1965	1970	1975
Total ATC User Penalties[1]	Lower Value Present Report	$7.85	$12.01	$16.70	$21.39
	Higher Value (URI Estimate)	11.0	16.40	21.80	26.00
Benefits From Reduction in User Penalties	Lower Value	3.93	6.01	8.35	10.70
	Higher Value	5.50	8.20	10.90	13.00
Benefits to the ATC System Itself		7.10	7.95	9.20	11.20
Total Benefits	Lower Value	11.03	13.96	17.55	21.90
	Higher Value	12.60	16.15	20.10	24.20

[1] See Table 56, pg. 168

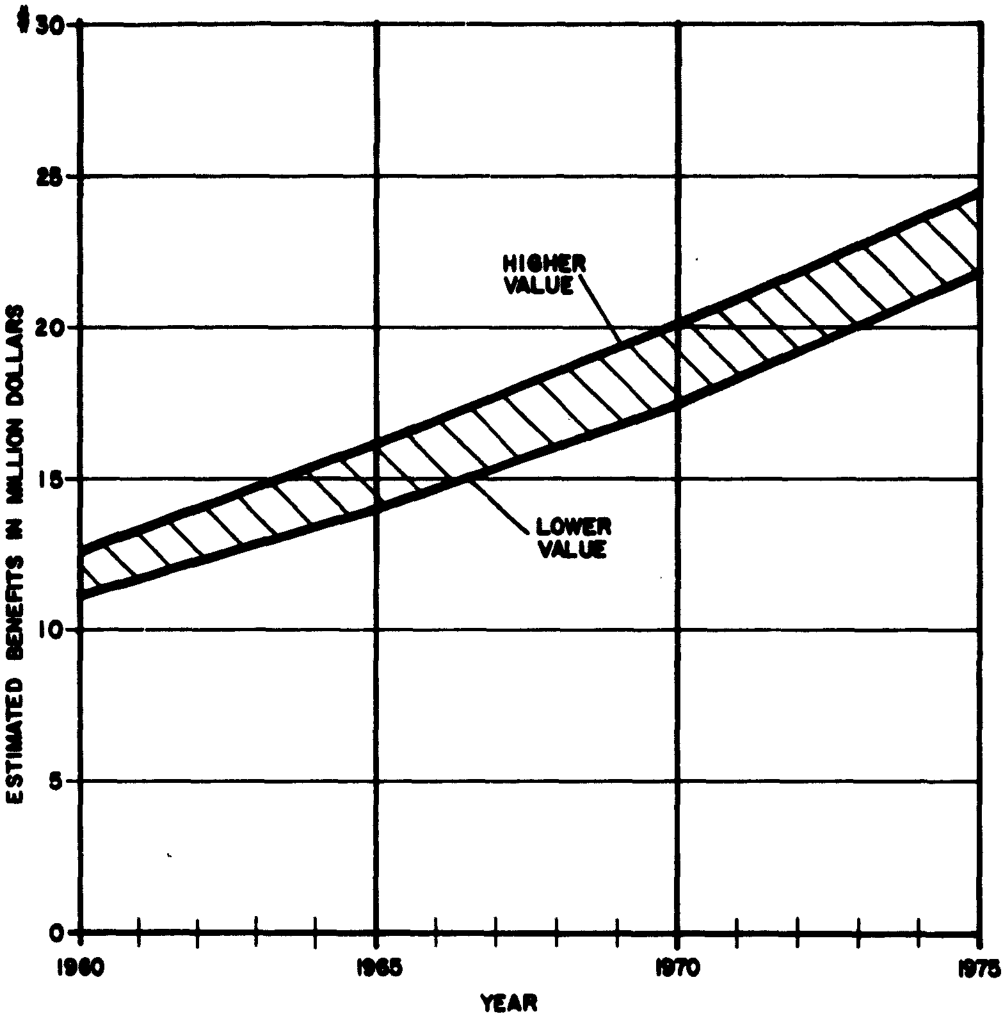

FIGURE 32. TOTAL ESTIMATED BENEFITS TO THE ATC SYSTEM AND SYSTEM USERS DUE TO IMPROVEMENTS IN THE NATIONAL AVIATION WEATHER SERVICES.

C. NET BENEFIT ANALYSIS

1. General Considerations

Public expenditures can be evaluated by a comparison between benefits and costs. The economic desirability of any new project is commonly measured in terms of the returns to be realized over a given period of time. Moreover, the marginal productivity of resources for a particular project should be at least equal to or greater than the benefits from other projects. While this is a primary factor in the determination of funding for a specific project, certain budgetary constraints, the amount and availability of monies, can be of equal significance.

In order to provide government agencies, engaged in the expenditures of public funds, with a valid yardstick for measuring the desirability and effectiveness of planned expenditures, the "stream" of benefits to be realized, and in particular the stream of net benefits (benefits less costs) accruing over the life of the project, must be brought back to the present and through summation combined into one representative dollar value. Similarly, the stream of capital expenditures and investments must be brought back to a "present value". The comparison of the present value of benefits with that of the costs is an important measure in the evaluation of expenditures and provides a rational basis for decision making concerning the outlay of public monies.

The method used here to assess the economic impact of the improvements in the national aviation weather services, in accordance with the CAWS design, has been widely employed in government economics and has been discussed in numerous economic treatises, a fairly comprehensive bibliography of which may be found in reference.[1]

The dollar benefits from and costs of the improvements in the national weather services have been computed for each year of the period in

[1] "Public Enterprise Economics and Transport Problems" by Tillo E. Kuhn, University of California Press, Los Angeles, 1962

question in these three categories: capital investment in equipment, operating costs including personnel and maintenance expenditures, and estimated dollar benefits.

As a next step the net benefits were determined by subtracting operating costs from total benefits for each year. The present values of these net benefits were calculated and summarized to obtain the total net benefit compressed into one meaningful dollar figure.

Finally, the present values of each year's capital investment were computed and summarized. The ratio of the sum of the present values of net benefits over the sum of the present values of capital investment provides one measure of the economic impact of the stipulated improvements in aviation weather support.

$$R = \frac{\Sigma B}{\Sigma C}$$

Where R = Benefit - Cost Ratio

ΣB = Sum of present values of net benefits (net benefits are defined as total benefits minus operating and maintenance costs).

ΣC = Sum of present values of capital equipment costs.

The interest rate (6%) used for computing present value reflects the costs of assets used today compared with assets a year from today. A given sum of money will have grown by 6% after a year's time. Consequently, a future expenditure or benefit, brought to the present, must be diminished by that same annual interest rate.

The chosen rate of 6% takes into account the value of capital in alternative private investment uses and the fact that most funds for Federal projects are generated by taxation.

Present values of costs and net benefits are computed using the following formula:

$$P = \frac{N}{(1 + r)^T}$$

where

P = sum of the present values of costs or net benefits

N = annual cost or net benefit

r = applicable interest rate (6%)

T = number of years from starting point (1963)

The starting point of the benefit-cost analysis is the year 1963, based on the assumption that implementation of the CAWS will commence during that year.

2. **Present Value of Capital Investment**

The estimated costs of Capital Equipment for the years 1963 to 1970 and the sum of their present values are shown in Table 79. It will be noted that after 1970 all capital outlays required to implement the CAWS design are considered to be completed.

Table 79. Cost of Capital Equipment and Present Value in Million Dollars

Year	CAWS Implementation	
	Cost of Equipment	Present Value
1963	3.71	3.71
1964	10.83	10.21
1965	17.93	15.96
1966	27.70	23.27
1967	20.61	16.32
1968	6.95	5.19
1969	2.07	1.46
1970	1.33	0.88
1971	0	0
1972	0	0
1973	0	0
1974	0	0
1975	0	0
Sum of Present Values:		$77.0 Million

3. Present Value of Net Benefits

a. Projected Total Benefits

In the preceding section all estimated benefits in the air carrier segment and the ATC system have been itemized and projected throughout the period 1960-1975. Table 80 below summarizes these total projected benefits. It will be noted that in two categories, namely the alternate fuel and the ATC user benefits both lower and upper estimated values have been quoted. These benefits, therefore, represent a range of values for each year, where the lower value is based on conservative estimates and the upper value is contingent on the removal of certain constraints, e.g., the 1000 foot ceiling "pad" of the alternate fuel requirement. As mentioned before, the benefits here are estimated beginning with the base year 1960, although the improvements will not be initiated until the year 1963. However, by starting the benefit tables and graphs with the year 1960 interpolation of intermediate values during the actual period of the CAWS implementation becomes possible.

Table 80. Total Projected Benefits, except General Aviation, For Period 1960-1975 (million dollars)

Benefits	1960	1965	1970	1975
Diversions	$1.89	$3.12	$3.94	$4.37
Cancellations	1.85	2.11	3.79	6.00
Delays:				
Enroute	2.86	4.45	6.86	9.54
Maintenance	0.87	1.13	1.30	1.42
Alternate and Contingency Fuel:				
Lower Value	1.10	8.17	15.51	22.89
(Upper Value)	(4.78)	(23.47)	(43.26)	(63.39)
ATC User Benefits				
Lower Value	3.93	6.01	8.35	10.70
(Upper Value)	(5.50)	(8.20)	(10.90)	(13.00)
ATC System Benefits	7.10	7.95	9.20	11.20
Sub Total				
Lower Value	19.60	32.94	48.95	66.12
(Upper Value)	$(24.85)	$(50.43)	$(79.25)	$(108.92)

Note: The estimated benefits in General Aviation have not been included in this table. They will be added later on.

The values in the above table have been plotted in Figure 33 below.

b. Adjusted Total Benefits

From the preceding section, where total benefits in all areas of carrier aviation were projected through the period of 1960 to 1975, a realistic appraisal of the time phasing of these benefits was made in recognition of the fact that the improvements are scheduled to be implemented beginning with the year 1963. The end of the implementation phase is in the 1969-1970 period. Shortly after this latter period the benefits are expected to be fully realized. Thus, the actual benefits will commence to be felt within the 1963-64 period and are expected to be 100% realized at the end of the implementation period of the improvements, by 1969-1970. It becomes therefore necessary to assign a factor of realization to the benefits which increases from zero to 100% during the transition period. The graph, Figure 34 depicts the estimated percentage values of realization of benefits through this period. At the beginning the benefits will be felt rather slowly. They will subsequently rise at a faster rate and will asymptotically approach full value shortly after completion of the CAWS. Applying this realization factor to the projected total benefits leads to the adjusted total benefits. These constitute a realistic estimate for the transition period 1963-1970. Table 81 shows in the first columns the interpolated projected benefits to the air carriers and the ATC system and its users for each year, covering the period 1963 to 1975. Both lower and upper values are given. The subsequent column lists the percent realization during the implementation period and the last two columns depict both lower and upper values of the adjusted total benefits. These adjusted total benefits, therefore, represent the estimated year to year dollar amounts to be saved in the total carrier and ATC operations through the planned improvements in the national aviation weather services as outlined by the CAWS design.

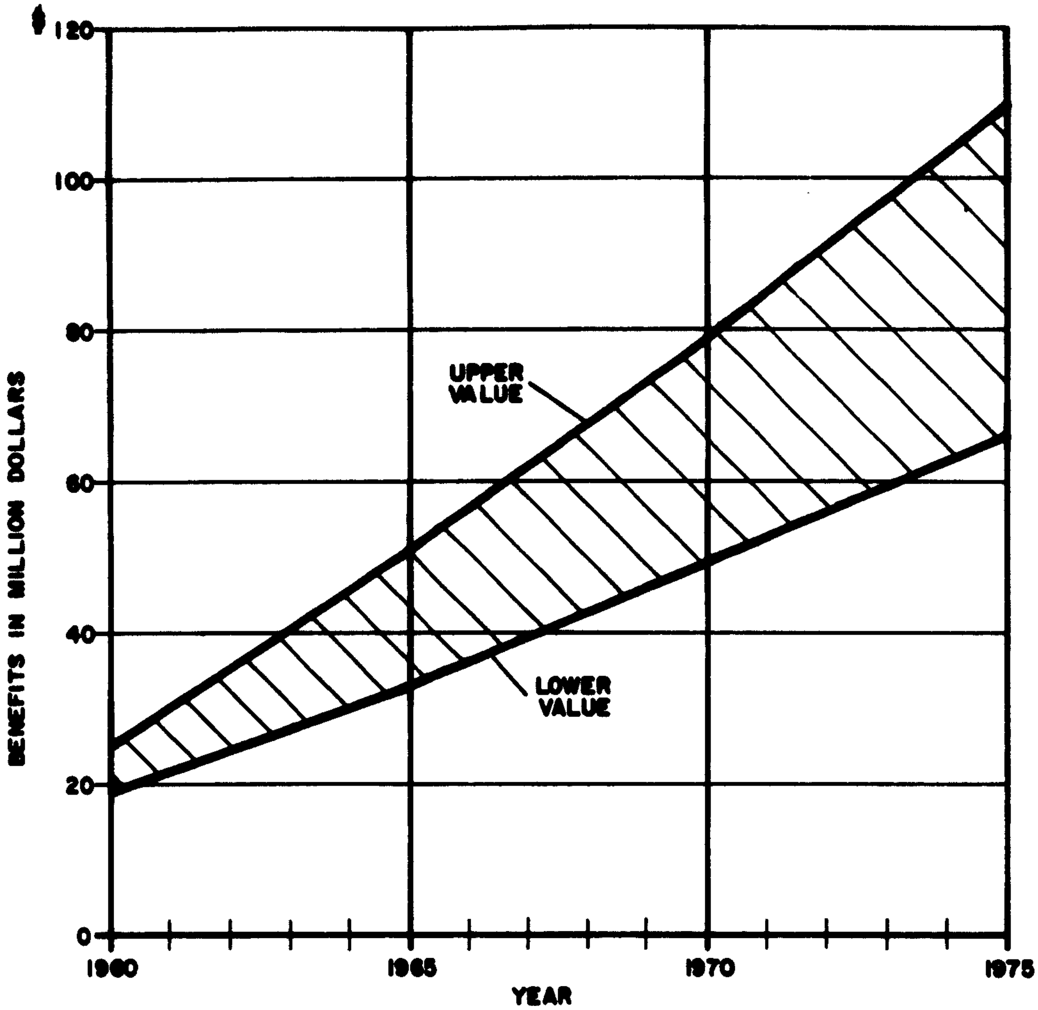

FIGURE 33. TOTAL PROJECTED BENEFITS, EXCEPT GENERAL AVIATION, FOR THE PERIOD 1960-1975 (IN MILLION DOLLARS)

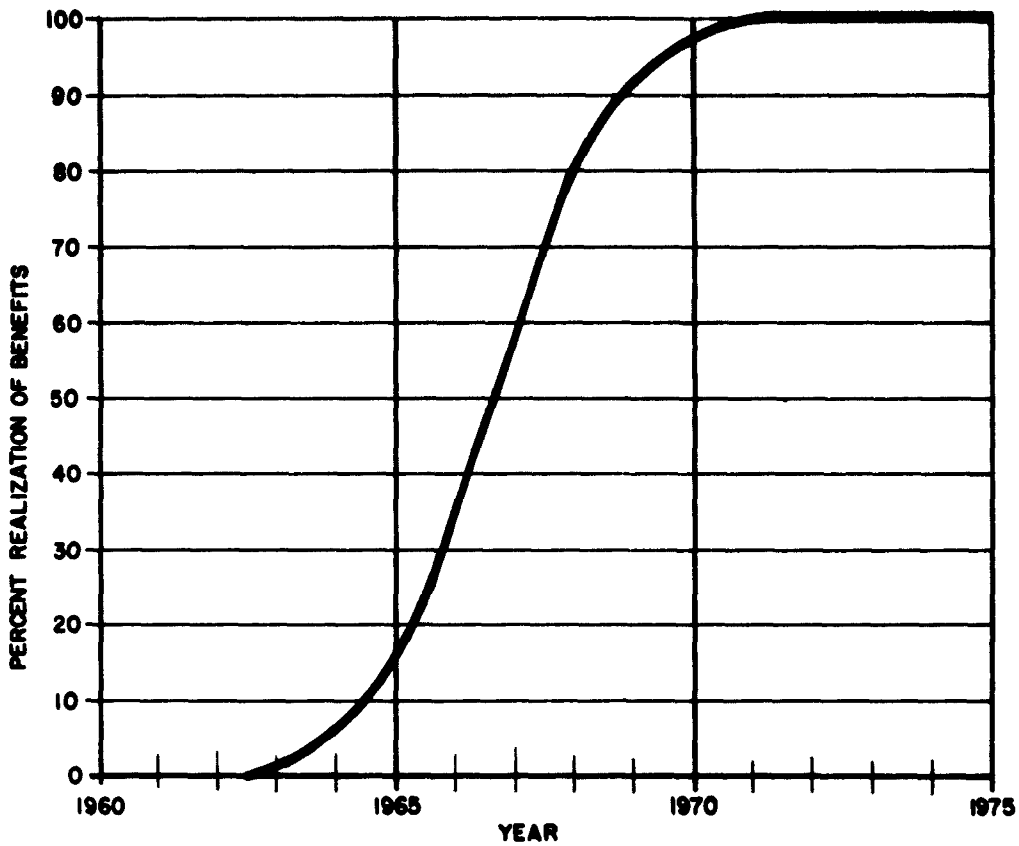

FIGURE 34. PERCENT REALIZATION OF BENEFITS IN THE 1960-1975 PERIOD

When comparing these values with the total costs of implementation, Table 60, it is seen that benefits from reduction in air carrier penalties alone will exceed the estimated improvement costs of $83.8 million starting approximately with the year 1971 where the upper value of the benefits has become $87.0 million. However, when the benefits to General Aviation are added,the total will exceed the cost for years earlier, in the 1966 period, see Figure 35.

Table 81. Adjusted Total Benefits, Air Carriers, ATC System and Its Users (In Million Dollars)

Year	Projected Total Benefits		Percent Realization of Benefits	Adjusted Total Benefits	
	Lower Value	Upper Value		Lower Value	Upper Value
1963	27.61	40.21	1%	0.27	0.40
1964	30.28	45.33	6	1.82	2.72
1965	32.94	50.43	17	5.60	8.57
1966	36.14	56.19	40	14.46	22.48
1967	39.34	61.95	60	23.60	37.17
1968	42.54	67.71	80	34.03	54.17
1969	45.74	73.47	92	41.98	67.59
1970	48.95	79.25	98	47.97	77.66
1971	52.38	85.22	100	52.38	85.22
1972	55.81	91.15	100	55.81	91.15
1973	59.24	97.08	100	59.24	97.08
1974	62.97	102.91	100	62.67	102.91
1975	66.12	108.92	100	66.12	108.92

Table 82 summarizes all estimated benefits to the air carrier, general aviation, and the ATC system and its users, i.e., all airspace users considered in this study to be derived from the implementation of the CAWS.

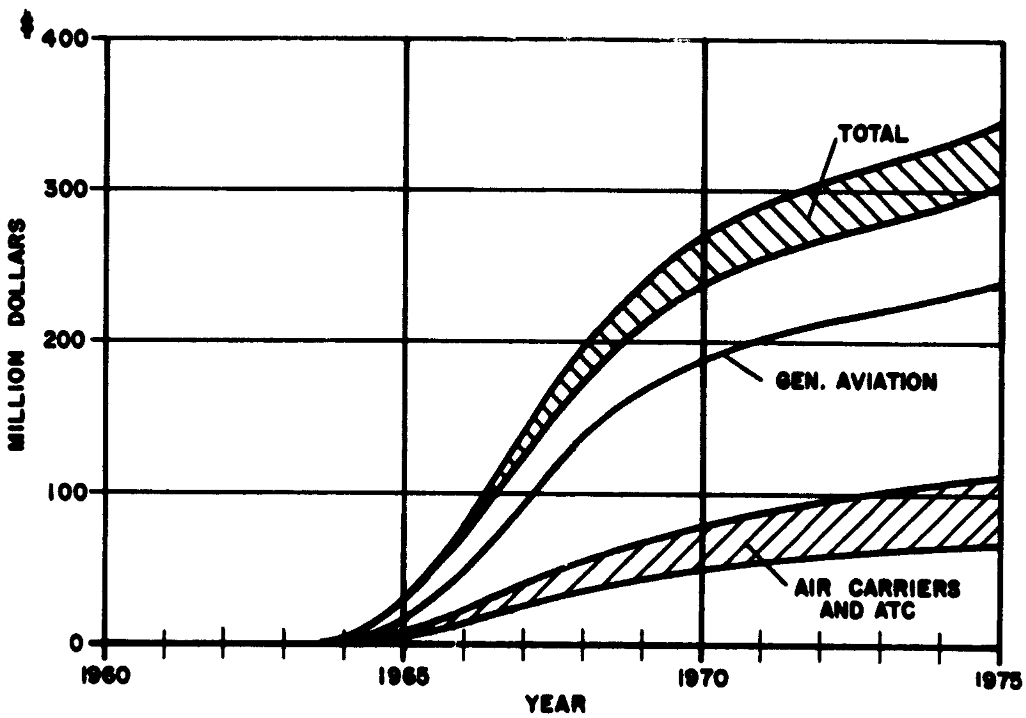

FIG. 35. ESTIMATED TOTAL DOLLAR BENEFITS FROM IMPROVEMENTS IN AVIATION WEATHER SERVICES

Table 82. Adjusted Total Benefits, (in Million Dollars)

Year	Adjusted Benefits General Aviation	Adjusted Benefits Other Airspace Users		Total Adjusted Benefits All Airspace Users	
		Lower Value	Upper Value	Lower Value	Upper Value
1963	1.49	0.27	0.40	1.76	1.89
1964	8.25	1.82	2.72	10.07	10.97
1965	27.10	5.60	8.57	32.70	35.67
1966	66.69	14.46	22.48	81.15	89.17
1967	104.61	23.60	37.17	128.21	141.78
1968	145.58	34.03	54.17	179.61	199.75
1969	174.46	41.98	67.59	216.44	242.05
1970	193.31	47.97	77.66	241.28	270.97
1971	205.68	52.38	85.22	258.06	290.90
1972	214.08	55.81	91.15	269.89	305.23
1973	222.54	59.24	97.08	281.78	319.62
1974	230.91	62.67	102.91	293.58	333.82
1975	239.34	66.12	108.92	305.46	348.26

c. Projected Net Benefits versus Costs

As a final step in the evaluation of benefits, the benefit-cost ratio must be determined. This ratio, in order to be representative, must include all three significant items; equipment cost, operating costs, and expected benefits. Since decisions concerning government expenditures in the area of aviation weather are influenced to a large extent by the initial capital investment in equipment pertaining to the four subsystems: observing, processing, communicating and presenting, these expenditures must be contrasted to the expected net benefits which are defined as total benefits less operating costs.

With such a comparison it is possible to compute a ratio of net benefits to expected equipment costs using the concept of present value as described under "General Considerations". It is necessary to consider present value here instead of merely the annual value. The reason is that any

future expenditure or benefit, when assessed in the present, would have a lower present value, based on the compound interest principle. If the "stream" of net benefits is computed over the 1963-1975 period, the present value of each annual net benefit can be assessed and then summed up into one value. This value, the sum of the present values of the net benefits, is shown in Table 83.

The left hand column shows the lower value, based on conservative assumptions, of $813.95 million; the right hand column shows the higher value of the benefits, based on contingencies and the expected relaxing of certain restrictions. The sum of the higher values is $993.00 million.

In order to arrive at a meaningful ratio, the sum of the present values of the net benefits has been divided by the sum of the present values of the capital equipment costs:

$$\frac{P_{NB}}{P_C} = \text{Benefit-Cost Ratio}$$

Table 83. Present Values of Net Benefits, Upper and Lower Values, In Million Dollars

Year	Present Values of Net Benefits	
	Lower Value	Upper Value
1963	-3.28	3.15
1964	-3.86	3.01
1965	+3.99	6.63
1966	26.00	32.73
1967	44.59	55.34
1968	75.43	90.48
1969	88.82	106.88
1970	93.86	113.61
1971	97.74	118.33
1972	98.08	119.00
1973	97.95	119.06
1974	97.65	118.85
1975	96.98	118.25
TOTAL	$813.95	$993.00

From a practical standpoint this ratio should be at least on the order of 2.5, i.e., the net benefits realised over a period of time should be at least 2.5 times the capital expenditures. From Table 78 the sum of the present values of capital expenditures is estimated to be ΣP_C = \$77.0 million. Dividing this sum into the lower and upper limits of the sum of the present values of the net benefits, we obtain:

$$\frac{\Sigma P_{NB_L}}{\Sigma P_C} = \frac{\$813.95 \text{ million}}{\$77.0 \text{ million}} = 10.6 \text{ (lower value)}$$

$$\frac{\Sigma P_{NB_U}}{\Sigma P_C} = \frac{\$993.0 \text{ million}}{\$77.0 \text{ million}} = 12.9 \text{ (upper value)}$$

These ratios, while they are not exact figures, nevertheless provide an order of magnitude estimate of the expected "pay-off" from the planned improvements in the national aviation weather services. Even if the necessary expenditures on capital equipment should turn out to be higher by a factor of two, thus reducing the benefit-cost ratio to 5.30 or 6.45 respectively, these values would still more than justify the implementation of the improvements.

It has been assume d throughout this analysis, that the life time of the equipment extends to 1975. This would constitute a period of from 5 to 12 years, since the implementation period of the capital equipment runs approximately from 1963 to 1970. However, from past experience with meteorological equipment, for example observing instrumentation, the effective life time with proper maintenance is frequently found to run from 15 to 20 years. This fact will increase the "stream" of net benefits considerably beyond the 1975 period, or more nearly to 1980. Consequently, with no corresponding increase in capital equipment expenditures, the benefit-cost ratio would be considerably increased over the present estimated values of 10.6 and 12.90 respectively.

It is felt, that the arbitrary termination of the expected equipment life with the year 1975 will render the ratios of our analysis somewhat low.

d. Total Benefits versus Costs

The total benefits and costs projected over the 1963-1975 period are shown in graphical form in Figure 36. Expected annual benefits on the order of 300.0 million in the 1970-1975 period and expected annual costs of 100 million during that time, result in an approximate factor of 3.0 by which the annual benefits are greater than the annual costs.

From the point of view of the entire program of improvements in the aviation weather services, it is of interest to contrast the present value of the "stream" of expected total benefits with that of the total costs. Table 84 lists the present values and the sums of the present values of total benefits and total costs.

Using the lower value of the expected benefits, a ratio of:

$$\frac{\Sigma P_{TB_L}}{\Sigma P_{TC}} = \frac{\$1442.61 \text{ million}}{711.24 \text{ million}} = 2.0$$

results. With the higher value of the benefits the ratio increases to

$$\frac{\Sigma P_{TB_U}}{\Sigma P_{TC}} = \frac{\$1621.68}{711.24} = 2.3$$

While this ratio does not reflect the expected returns from capital investment which the Government must make in order to implement the improvements in the national aviation weather services, it does provide a measure of the benefit margin over and above the annual stream of the total costs: equipment, maintenance and operations. Here again, the ratio could be somewhat increased by extending the period beyond 1975, say to 1980, since the increase in

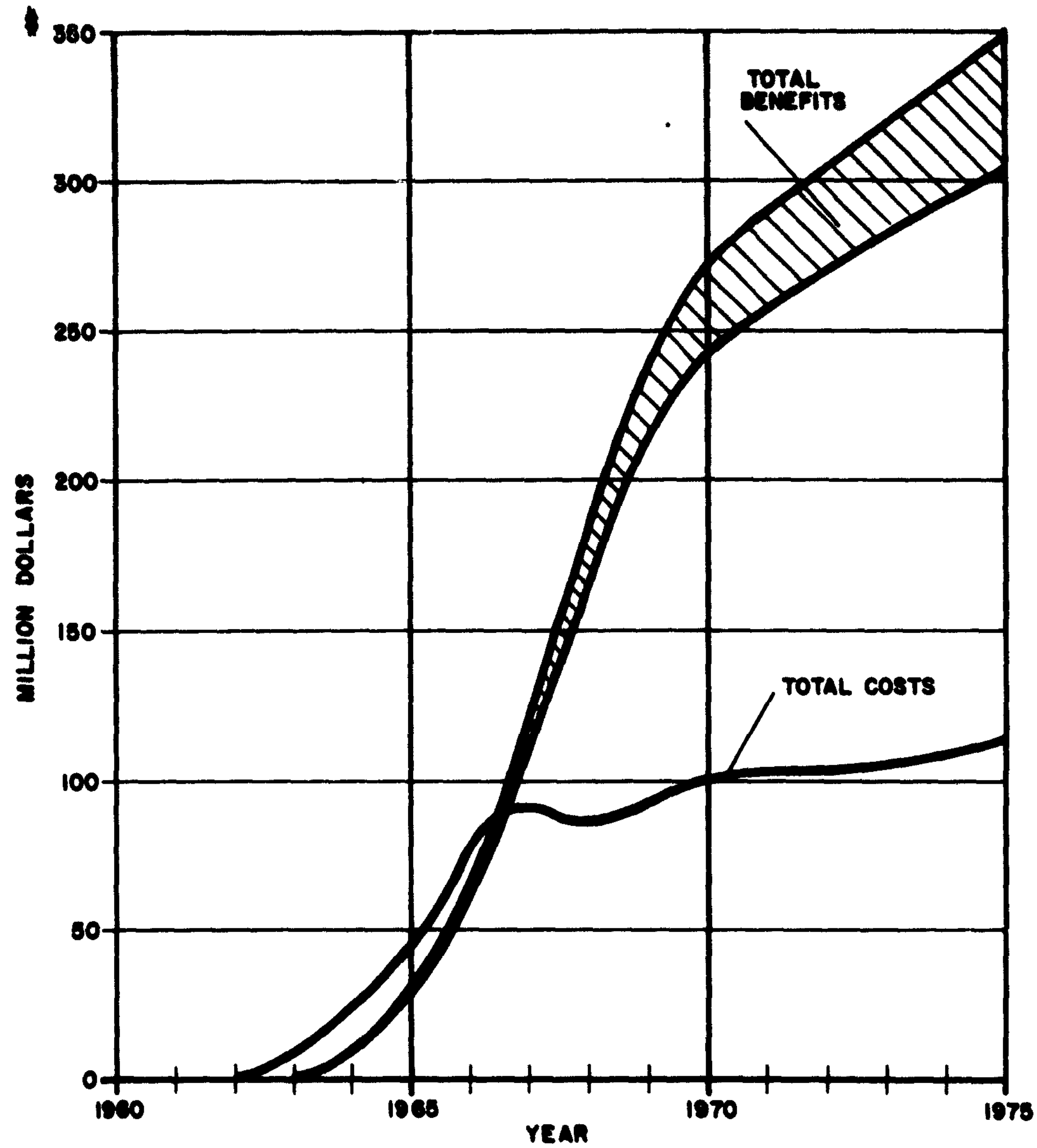

FIG. 36. PROJECTED TOTAL COSTS AND TOTAL BENEFITS, DUE TO CAWS IMPLEMENTATION

Table 84. Present Values of Total Benefits and Total Costs 1963-1970, in Million Dollars

Year	Present Value, Total Adjusted Benefits		Present Value Total Costs
	Lower Value	Upper Value	
1963	1.76	$1.89	$8.75
1964	9.50	10.34	21.35
1965	29.10	31.75	41.07
1966	68.17	74.90	73.22
1967	101.54	112.29	73.28
1968	134.17	149.21	63.93
1969	152.59	170.65	65.23
1970	160.45	180.20	67.47
1971	161.80	182.39	64.06
1972	159.77	180.70	61.69
1973	157.23	178.35	59.29
1974	154.72	175.92	57.07
1975	151.81	173.09	54.83
Sum	$\Sigma P_{TB_L} =$ $1442.61	$\Sigma P_{TB_U} =$ $1621.68	$\Sigma P_{TC} =$ $711.24

benefits is likely to be greater than the increase in annual costs. (Strictly speaking, a benefit/cost ratio greater than unity would economically justify a project.) The above ratio of 2.0 and 2.3 therefore provides a comfortable margin of economic justification subject to the returns available from alternative programs. This justification is enhanced by the fact that numerous intangible benefits, as outlined in the next section, have not been included in this ratio. These benefits, while not readily assessible in terms of dollars, can be of considerable value to the economy as a whole.

4. **Intangible Benefits**

In addition to those benefits which can be assessed in dollars, there are others that are of a more intangible nature. Although these benefits, too, basically possess a dollar value, it has not been found feasible within the scope of this study to compute or estimate their value. Such intangible benefits, when analyzed in detail, may well run into tens of millions of dollars annually.

For the purpose of this study a brief listing of these non-assessable benefits resulting from the planned improvements in the national aviation weather services will suffice.

- Increased Passenger Comfort
  Greater avoidance of areas of atmospheric turbulence, and the possibility of waiting out critical weather occurrences on the ground rather than in a traffic holding pattern, will avoid passenger discomfort.

- Increased Demand for Air Travel
  Better weather information will result in improved flight planning and better on-time performance. The resulting improved reliability of air travel can be expected to produce an increase in public demand.

- Reduction of Overloads in the Air Traffic Control System
  It is a fact that presently the ATC system reacts more to weather crises than it plans for them. With the projected improvements in the system, because of better advance planning, some of the peak loads brought about by unexpected weather conditions will be reduced. Moreover, more accurate weather knowledge on the part of the controller will add an element of confidence to his work which will ultimately be reflected in the efficiency of the control system.

- **Benefits to Military Aviation**

  Military aviation receives major support from the civil weather service. Improvements in the civil weather system will result in corresponding benefits to military aviation.

- **Reduction in Air Mail and Air Cargo Delays**

  The present penalties suffered by Air Mail and Air Cargo have not been assessed in terms of dollars. However, from conferences with U. S. Post Office personnel and Air Cargo managers it was ascertained that the disruptions caused by unanticipated weather are of considerable magnitude. Implementation of the CAWS design is expected to result in a definite decrease in these disruptions.

- **Increased Safety in IFR Flying**

  The stipulated extensive use of improved weather information by the ATC system is expected to increase the safety margin in IFR flying, particularly in the General Aviation and Military Aviation user categories. While generally the weather accident rate of aircraft flying IFR is low, a substantial decrease in potential accidents and near misses may be expected.

- **CVR Operations**

  The report of the President's Task Force on Air Traffic Control, "Project Beacon", recommends a new category of aircraft control called Controlled Visual Rules (CVR). The expanded weather support to the ATC which will result from the planned improvements will be a necessity for the implementation of CVR flight.

- **<u>Benefits to Non-Aviation Users</u>**

  The non-aviation segments of the economy derive appreciable benefits from the aviation weather service. Improvements in this service will result in benefits to the economy as a whole.

- **<u>Loss of Aircraft Utilization</u>**

  A decrease in aircraft delays due to weather causes will result in better utilization of equipment and a more economical operation.

APPENDICES

APPENDIX A

Alternate Fuel Carried by Piston and Turbojet Carrier Aircraft September 1961, Chicago O'Hare Airport

APPENDIX B

Direct Flight Cost Per Total Hour by Aircraft Types. Calendar Year Ended December 31, 1960 (In Dollars)

APPENDIX C

Major Trunk Carrier Enroute Delay Sampling

APPENDIX D

On-Time Performance Statistics

APPENDIX E

Analysis of Correction Factor Applied to ATC Delays

APPENDIX F

Ontario Air-Carrier Diversions

APPENDIX G

Acknowledgements

APPENDIX A

Table A-1. Alternate Fuel Carried by Piston and Turbojet Carrier Aircraft, September 1961, Chicago O'Hare Airport

APPENDIX A

Table A-1. Alternate Fuel Carried by Piston and Turbojet Carrier Aircraft, September 1961, Chicago O'Hare Airport

PISTON AIRCRAFT					TURBOJETS		
Date	No. of Flights	Total Trip Length Minutes	Alternate Fuel Lbs.	No. of Alternates	No. of Flights	Alternate Fuel Lbs.	No. of Alternates
Sept.							
1	69	5554	101,200	65	38	252,000	31
2	59	4842	64,400	46	32	148,000	25
3	63	5956	149.900	57	40	278,000	28
4	64	5380	132,300	61	44	224,000	35
5	85	6556	177,900	75	41	184,000	31
6	85	6744	88,400	50	44	241,000	29
7	83	6577	95,700	55	60	329,000	47
8	88	7218	74,500	57	45	190,000	30
9	80	5217	89,600	53	42	136,000	22
10	82	6797	77,700	47	42	148,000	24
11	81	6855	141,600	73	41	227,000	33
12	79	6800	281,200	70	42	285,000	32
13	84	6835	215,000	70	42	343,000	35
14	83	6636	112,500	59	40	216,000	30
15	85	7000	13,300	9	41	60,000	9
16	85	6933	6,100	4	43	30,000	3
17	82	6780	8,000	6	42	112,000	17
18	85	7011	18,800	11	41	138,000	21
19	85	7003	61,200	26	40	144,000	18
20	85	7110	109,600	50	42	317,000	37
21	87	7173	130,900	61	37	172,000	27
22	87	7173	131,200	64	40	206,000	27
23	86	7087	165,800	59	42	266,000	31
24	82	6927	146,500	43	42	318,000	30
25	85	6903	86,900	41	41	133,000	19
26	87	7113	26,500	15	43	202,000	26
27	86	7013	35,200	19	40	90,000	12
28	88	7218	15,500	9	42	66,000	11
29	87	7138	88,580	45	41	186,000	29
30	80	6866	161,800	60	40	256,000	28
Total	2447	200,155	3,007,700	1,360	1250	5,897,000	777

Total Reported Flights (Jets and Propellers): 3,697

Total Alternate Fuel Ferried: 8,904,700 pounds

APPENDIX B

Table B-1. Direct Flight Cost Per Total Hour by Aircraft Types - Calendar Year Ended December 31, 1960 (In Dollars)

Table B-1. Direct Flight Cost Per Total Hour by Aircraft Types
Calendar Year Ended Dec. 31, 1960 (In Dollars)

Turbo-Jet Aircraft Four Engine	Flying Oper. Less Rentals	Direct Maint.	Indirect Maint.	Total Maintenance	Depre-ciation	Rentals	Total	Total Hours Flown
B-707-100-200 DOM								
American	377.23	165.12	130.49	295.61	121.13		793.97	75,285
Braniff	448.56	244.78	44.68	289.46	201.99		940.01	6,801
Trans World	379.50	217.86	101.31	319.17	60.23	257.64	1016.54	48,614
Continental	392.05	152.28	48.54	200.82	119.75	.38	713.00	18,502
Western	409.22	194.29	36.06	230.35	58.25	346.63	1044.45	3,298
B-707-100-200 INT								
Braniff	536.43	241.76	47.38	289.15	205.07		1030.65	1,643
PAA-LAD	575.61	245.08	183.11	428.19	338.20		1342.00	10,911
B-707-30000 M								
Trans World	540.57	171.87	64.24	236.11	227.90		1004.58	7,830
B-707-300 INT								
PAA-Alaska	740.71	163.73	122.70	286.43	249.33		1276.47	1,030
PAA-Atlantic	592.25	167.31	125.11	292.42	247.88	1.70	1134.25	32,017
PAA-CAD	579.07	164.96	145.11	310.07	253.82		1142.96	1,110
PAA-Pacific	563.02	172.37	143.95	316.32	247.01		1126.35	30,407
Trans World	448.97	178.44	67.59	246.03	93.34	175.82	964.16	21,906
B-720 DOM								
American	399.80	60.91	58.08	118.99	102.42	60.68	681.89	7,714
United	303.19	92.29	64.85	157.15	171.70		632.04	11,114
CV-880 DOM								
Delta	423.04	131.43	101.29	232.72	210.71	4.49	870.96	6,676
Northeast	542.99	282.24	297.83	580.06		219.61	1342.66	202
DC-8-10 DOM								
Delta	414.08	226.24	139.09	365.33	236.10		1015.51	12,988
United	405.19	158.13	134.73	292.86	187.36		885.41	61,796
DC-8-10 INT								
United	507.02	158.64	143.68	302.32	194.24		1003.58	7,792
DC-8-20 DOM								
Eastern	406.83	140.37	56.64	197.01	231.89		853.73	14,248
National	481.74	193.99	93.94	287.93	254.67		1024.34	3,551

Table B-1. Direct Flight Cost Per Total Hour by Aircraft Types, (Cont'd.)

Turbo-Jet Aircraft Four Engine	Flying Oper. Less Rentals	Direct Maint.	Indirect Maint.	Total Maintenance	Depre-ciation	Rentals	Total	Total Hours Flown
DC-8-20 INT								
Eastern	517.38	172.83	65.47	238.32	284.32		1040.02	2,089
DC-8-30 DOM								
Northwest	615.68	321.92	54.28	276.20	894.78		1786.66	299
DC-8-30 INT								
Northwest	742.66	167.20	59.08	226.28	651.85		1620.79	1,155
PA ATL	586.44	171.76	116.55	288.31	225.94	60.97	1161.66	13,436
PA LAO	626.43	187.25	138.04	325.29	273.20	49.05	1273.97	2,535
Panagra	611.80	382.86	22.66	405.53	308.48		1325.81	1,899
Turbo-Prop Aircraft Twin Engine								
CV-540 DOM								
Allegheny	116.14	79.99	26.59	101.58	22.35	1.56	241.63	3,116
F-27 DOM								
Aloha	93.99	52.20	10.05	62.25	39.12		195.36	9,771
Bonanza	86.60	57.60	13.89	71.49	2.70		180.79	17,691
Ozark	87.62	74.32	14.14	88.46	25.59		201.67	6,736
Pacific	88.71	74.51	29.74	104.25	29.50		222.46	12,984
Piedmont	92.71	68.59	19.19	87.78	24.33		204.82	17,684
West Coast	87.76	62.66	15.80	78.46	16.67		182.89	16,951
Turbo-Prop Aircraft Four Engine								
L-188 DOM								
American	174.05	173.75	67.12	240.87	99.63	64.38	578.93	73,836
Braniff	165.74	168.00	43.94	211.94	108.54		486.22	15,198
Eastern	179.80	98.97	31.52	130.49	130.31		440.60	101,638
National	176.35	138.82	37.78	176.60	123.60		476.55	28,596
Northwest	180.89	116.14	44.34	160.48	92.18		433.55	25,747
Western	165.72	160.58	26.02	186.60	83.95	50.78	487.05	16,839

Table B-1. Direct Flight Cost Per Total Hour by Aircraft Types, (Cont'd.)

Turbo-Prop Aircraft Four Engine	Flying Oper. Less Rentals	Direct Maint.	Indirect Maint.	Total Maintenance	Depreciation	Rentals	Total	Total Hours Flown
L-188 INT								
Eastern	209.29	105.22	39.99	145.21	134.65		489.15	1,043
V-700 DOM								
Capital	119.14	51.82	31.45	83.27	47.59	.	250.00	184,525
Northeast	115.53	65.24	34.84	100.08	58.18		273.79	26,188
V-800 DOM								
Continental	123.57	60.28	24.28	84.56	52.26		260.39	37,246
Piston Engine Aircraft Twin Engine								
DC-3 DOM								
Allegheny	65.79	21.50	13.76	35.27	4.03		105.09	18,917
Aloha	59.87	51.16	43.05	94.20	23.19		177.26	4,997
Bonanza	58.11	28.93	7.24	36.17	13.60		107.88	7,440
Capital	63.57	22.41	14.34	36.75	4.59		104.91	20,623
Central	55.48	24.64	11.68	36.32	3.39	2.76	97.95	28,221
Continental	67.94	20.77	10.47	31.24	1.18	13.30	113.66	21,374
Frontier	58.75	20.73	15.57	36.31	7.71	.46	103.23	52,014
Hawaiian	67.25	26.40	11.67	38.07	4.10		109.42	7,614
Lake Central	54.67	19.75	7.26	27.01	2.66	1.74	86.08	27,167
Mohawk	62.08	23.74	16.11	39.84	2.65		104.57	12,113
North Central	55.83	21.73	10.44	32.17	4.27	2.86	95.13	88,173
Northeast	60.86	36.58	27.04	63.62	6*	.30	124.72	23,683
Ozark	53.66	22.14	14.17	36.31	3.07	1.30	94.34	55,316
Pacific	64.09	28.01	11.37	39.38	3.18		106.65	8,025
Piedmont	64.29	25.87	12.33	38.20			102.49	28,644
Southern	52.90	19.37	15.66	35.03	5.87	.84	94.64	40,907
Trans-Texas	50.12	22.34	7.55	29.88	4.41	.92	85.33	52,059
West Coast	59.85	22.28	9.31	31.59	3.22		94.66	27,672
DC-3 INT								
Caribbean	58.05	33.48	9.56	43.04	7.77		108.86	11,489
Pac Northern	76.71	30.00	11.91	41.91	4.78		123.40	4,836

Table B-1. Direct Flight Cost Per Total Hour by Aircraft Types (Cont'd.)

Piston Engine Aircraft Twin Engine	Flying Oper. Less Rentals	Direct Maint.	Indirect Maint.	Total Maintenance	Depre-ciation	Rentals	Total	Total Hours Flown
C-46 DOM								
AAXICO	61.40	30.62		30.62	14.04	4.46	110.52	43,347
Riddle	78.38	29.09	7.95	37.04	10.33	9	125.84	29,830
C-46 INT								
Aerovias	78.45	37.44	12.49	49.93	4.17	5.29	137.84	2,714
Alaska	108.22	51.47	50.68	102.14	28.70		239.06	2,028
Riddle	82.21	30.69	12.58	43.26	11.92	.16	137.55	2,055
M-202 DOM								
Allegheny	92.91	47.72	29.12	76.84	11.80	1	181.56	21,950
Pacific	87.44	47.13	16.78	63.91	15.81	3.60	170.76	9,204
M-404 DOM								
Eastern	93.51	32.28	17.12	49.41	1.47		144.39	121,061
Pacific	94.19	48.67	20.19	68.86	9.53	3.72	176.30	8,691
Trans World	108.01	48.64	42.25	90.89	6.10		205.00	39.132
CV-240 DOM								
American	99.80	44.69	47.97	92.67	3.14		195.61	79,419
Mohawk	96.74	64.82	30.45	95.27	29.72	2.50	224.23	16,647
Western	96.16	43.39	18.99	62.39	10.72		169.27	8,284
CV-340-410 DOM								
Allegheny	94.07	55.71	19.85	75.57	22.89		192.53	10,133
Braniff	98.14	38.04	23.39	61.42	16.68		176.24	75,689
Delta	93.10	38.28	26.02	64.30	22.29		179.69	73,735
Eastern	86.65	25.71	17.73	43.44	37.63		167.72	53,699
Frontier	96.76	58.15	21.96	80.12	24.74		201.62	9,157
Hawaiian	107.80	49.04	21.73	70.78	31.94		210.52	12,999
Mohawk	92.25	38.98	12.68	51.66	39.35		183.26	12,267
National	91.96	40.03	27.63	67.66	34.97		194.59	17,868
North Central	90.89	78.98	34.66	113.64	16.41		220.94	12,547
United	110.64	38.21	36.87	75.08	26.40		212.12	52,942

Table B-1. Direct Flight Cost Per Total Hour by Aircraft Types, (Cont'd.)

Four Engine	Flying Oper. Less Rentals	Direct Maint.	Indirect Maint.	Total Maintenance	Depre-ciation	Rentals	Total	Total Hours Flown
Four Engine								
B-377 DOM								
Northwest	197.22	58.79	44.70	103.49		5.90	306.61	6,519
B-377 INT								
PAA-Alaska	255.15	67.58	42.16	109.74	42.70		407.59	2,783
PAA-Pacific	306.14	50.10	46.05	96.15	40.89		443.18	17,535
DC-4 DOM								
Capital	103.99	56.59	33.45	90.03	5.46		199.48	24,996
Northwest	98.90	52.69	32.25	84.94	4.95	4.92	193.71	26,208
Riddle	102.56	57.77	16.86	74.63	18.90	25.95	222.04	2,239
Slick	85.13	50.82	14.52	65.34	3.70	30.17	184.34	12,840
DC-4 INT								
Aerovias	236.36	100.87	26.13	127.01	9.67	34.85	407.89	2,471
Alaska	140.69	71.61	49.52	121.13	2.60	20.61	285.03	3,227
Mackey	80.94	71.52	13.48	85.00	31.36		197.30	3,286
PAA-Atlantic	171.97	53.35	52.66	106.00	22.52		300.49	12,180
PAA-LAD	117.54	43.21	45.56	88.76	17.09		223.39	24,339
Resort	82.17	45.75		45.75	12.26	11.51	151.69	14,521
Riddle	114.66	57.40	15.70	73.10	21.47	30.11	239.34	4,114
Seaboard	128.68	82.17	32.27	114.43	16.36	90.91	350.38	3,564
DC-6 DOM								
American	161.41	65.76	75.45	141.21	2.55	.99	306.16	109,331
Braniff	156.19	71.16	45.56	116.72	8.56		281.47	25,476
Delta	145.70	73.69	35.07	198.76	1.29	25.10	280.85	35,815
National	156.61	99.46	75.41	174.87	2.78*		328.70	6,557
United	173.31	53.60	54.37	107.97	1.40		282.68	78,052
DC-6 INT								
Alaska	191.38	57.56	34.20	91.76	40.46	14.23	337.83	9,217
American	152.62	63.52	34.03	97.55	2.41	1.49	254.07	4,054
Trans Corp	159.42	99.96	11.30	111.26	48.69	6.65	326.02	11,332
DC-6A DOM								
American	162.50	84.59	95.47	180.06	134.08		476.64	10,310
Hawaiian	198.68	80.53	35.36	115.88	45.48	40.73	400.77	4,740

Table B-1. Direct Flight Cost Per Total Hour by Aircraft Types, (Cont'd.)

Four Engine (cont'd.)	Flying Oper. Less Rentals	Direct Maint.	Indirect Maint.	Total Maintenance	Depre-ciation	Rentals	Total	Total Hrs. Flown
DC-6A DOM(Cont'd.)								
Slick	177.43	54.78	14.84	69.62	113.38	35.54	395.97	2,298
United	175.13	53.41	52.84	106.25	69.61		350.99	16,553
DC-6B DOM								
American	168,71	71.66	84.95	156.61	5.37	8.59	339.28	42,179
Capital	181.23	81.76	27.69	109.46	11.53	61.49	369.71	22,069
National	159.11	101.82	83.37	185.20	52.02		396.33	13,030
Northeast	154.32	67.12	36.90	104.02	47.09		305.43	36,883
Northwest	169.53	55.13	32.77	87.91	59.13	16.94	333.51	41,875
United	177.09	50.61	49.60	100.22	46.04	1.45	324.80	81,567
Western	155.48	44.27	14.26	58.53	79.85		293.86	69,008
DC-6B INT								
Eastern	165.06	30.18	26.82	57.00	15.20	130.79	368.05	20,044
Northwest	199.90	53.77	33.22	86.99	61.53	19.96	368.38	24,099
PAA-Atlantic	233.80	69.12	63.47	132.59	78.78		445.17	18,639
PAA-LAD	190.62	68.12	66.15	134.31	79.14	5	404.12	41,191
Panagra	217.57	152.18	8.01	160.19	19.53		397.29	4,611
United	188.34	50.84	57.74	108.58	73.32		370.24	3,347
Western	175.44	52.91	16.96	69.87	95.45		340.76	8,474
DC-7 DOM								
American	212.05	106.24	98.82	205.06	177.63		594.74	46,763
United	217.39	92.64	77.39	170.03	135.74		523.16	118,277
DC-7 INT								
American	137.07	88.94	41.25	130.19	168.92		456.18	4,655
DC-7B DOM								
Continental	229.25	120.89	66.25	187.14	206.61		623.00	7,858
Eastern	193.19	85.69	31.93	117.62	83.43		394.24	119,817

Table B-1. Direct Flight Cost Per Total Hour by Aircraft Types, (Cont'd.)

Four Engine (cont'd.)	Flying Oper. Less Rentals	Direct Maint.	Indirect Maint.	Total Maintenance	Depre-ciation	Rentals	Total	Total Hours Flown
DC-7B INT								
Eastern	208.42	95.56	36.16	131.74	99.09		439.25	17,137
PAA-LAD	230.30	60.79	58.51	119.30	179.06	23	528.89	12,665
Panagra	222.35	165.45	13.43	178.87	85.87		487.09	10,531
DC-7-7B DOM								
Delta	186.69	103.05	71.47	174.52	101.13		462.34	44,745
National	188.56	91.22	61.87	153.09	121.95		463.60	11,158
DC-7-7B INT								
Delta	209.83	110.63	68.79	179.41	108.41		497.65	4,348
National	185.35	96.14	66.48	162.63	122.63		470.61	1,535
DC-7C DOM								
Braniff	201.70	118.78	47.66	166.45	75.63		443.78	10,108
Northwest	200.20	96.26	46.67	142.93	80.00	27.54	450.67	43,247
DC-7C INT								
Braniff	234.15	115.98	48.72	164.70	81.09		479.94	7,684
Northwest	256.66	94.46	46.67	141.13	80.56	26.94	505.29	16,959
PAA-Atlantic	297.63	85.16	79.70	164.86	155.25		617.74	34,441
PAA-LAD	213.17	72.57	49.84	122.41	166.30		501.88	12,664
PAA-Pacific	285.87	99.33	89.06	188.40	179.35		653.62	16,420
DC-7F DOM								
American	214.99	89.15	80.35	169.50	133.21		517.70	19,615
L-49 DOM								
Capital	151.59	71.97	43.33	115.30	52.15	1.50	320.54	10,269
Trans World	171.42	67.98	57.96	123.95	11.06		308.43	71,494
L-749 DOM								
Eastern	177.49	5.81	30.32	36.12	9.48		223.09	10,132
Trans World	171.42	67.98	57.96	123.95	11.06		308.43	71,494
L-749 INT								
PAC Northern	184.16	75.52	31.46	106.98	60.19	2.11	353.44	15,494

Table B-1. Direct Flight Cost Per Total Hour by Aircraft Types, (Cont'd.)

Four Engine (cont'd.)	Flying Oper. Less Rentals	Direct Maint.	Indirect Maint.	Total Maintenance	Depre-ciation	Rentals	Total	Total Hours Flown
L-1049 DOM								
Eastern	181.23	82.48	44.93	127.41	7.02		315.66	27,378
Trans World	201.48	133.30	110.20	243.51	29.09		474.08	7,701
L-1049C DOM								
Eastern	184.37	92.65	40.36	133.01	8.11		325.49	31,845
L-1049C INT								
Eastern	159.04	71.94	21.87	93.80	32.69		285.53	3,253
L-1049G DOM								
Eastern	210.82	70.34	35.52	105.86	125.21		441.89	21,879
Trans World	209.65	105.83	74.57	180.40	133.92		523.97	64,484
L-1049H DOM								
Flying Tiger	226.88	119.18	38.83	158.01	99.00	17.44	501.33	38,627
National	200.77	116.34	72.01	188.35	158.55		547.67	7,609
Slick	204.33	100.93	20.51	121.44	62.72	50.87	439.36	13,381
Trans World	215.02	75.76	60.98	136.74	86.82	122.60	561.18	10,861
L-1049H INT								
Seaboard	256.33	148.03	58.09	206.13	35.09	107.43	604.98	21,878
Trans World	319.18	81.93	85.10	167.03	67.14	135.00	688.35	6,753
L-1649A DOM								
Trans World	222.00	118.62	79.77	198.39	193.42		613.81	31,041
L-1649A INT								
Trans World	316.19	125.42	84.19	209.61	177.29		703.09	26,080

Table B-1. Direct Flight Cost Per Total Hour by Aircraft Types, (Cont'd.)

Helicopter	Flying Oper. Less Rentals	Direct Maint.	Indirect Maint.	Total Maintenance	Depre-ciation	Rentals	Total	Total Hours Flown
B-470 DOM Chicago	22.78	14.98	9.92	24.89	9.62		57.29	3,652
S-55 DOM Los Angeles	34.44	31.64	14.30	45.94	6.06		86.44	9,242
S-58 DOM Chicago	68.51	70.17	23.78	93.95	42.18		204.64	10,538
V-44 DOM New York	94.21	80.07	21.37	101.44	53.86		249.51	8,362

Source: CAB Form 41. Excludes those operations involving a relatively minor amount of experience.

APPENDIX C

Major Trunk Carrier Enroute Delay Sampling

Table C-1. Major Trunk Carrier Enroute Delay Sampling
Turbojet

Period	Number of Trips Reported	Number of Trips Delayed by Weather	Average Minutes per Weather Delay	Number of Trips Delayed by Winds	Average Minutes per Wind Delay	Number of Trips Gains Due to Weather	Average Minutes per Weather Gain	Number of Trips Gains Due to Winds	Average Minutes per Wind Gain	Percent Total Trips with Delays	Percent Total Trips with Gain
Aug'60	2956	883	7.5	769	7.7	710	8.6	626	8.7	30	24
Sept.	3291	740	6.6	611	6.7	852	8.6	810	8.8	23	26
Oct.	3885	902	7.1	735	7.4	1100	8.9	1023	9.0	23	28
Nov.	3976	822	6.2	700	6.4	1370	8.8	1276	8.8	21	34
Dec.	3980	896	6.9	769	7.1	1609	9.4	1509	9.5	22	40
Jan'61	4102	838	6.7	735	6.8	1708	8.5	1576	8.7	20	41
Feb.	3936	969	6.7	812	6.9	1496	8.4	1394	8.0	24	37
Mar.	4820	1190	6.7	996	7.0	1888	8.3	1757	8.5	25	39
April	4780	1141	7.3	926	7.2	1982	8.3	1841	8.5	24	41
May	5820	1354	6.4	1044	6.7	2297	6.8	2150	6.9	23	40
June	6219	1404	5.6	1021	5.6	2094	6.4	1879	6.5	23	32
July	7115	1557	5.3	1065	6.2	2090	6.5	1885	6.0	22	29

Table C-1. Major Trunk Carrier Enroute Delay Sampling (Cont'd.)

Propeller

Period	Number of Trips Reported	Number of Trips Delayed by Weather	Average Minutes per Weather Delay	Number of Trips Delayed by Winds	Average Minutes per Wind Delay	Number of Trips Gains Due to Weather	Average Minutes per Weather Gain	Number of Trips Gains Due to Winds	Average Minutes per Wind Gain	Percent Total Trips with Delays	Percent Total Trips with Gain
Aug'60	24166	4042	4.2	2985	3.9	11200	5.4	9862	5.6	16.8	46.5
Sept.	22312	3497	4.0	2786	3.9	10190	5.4	9045	5.5	15.8	45.5
Oct.	22073	3789	4.6	3146	4.7	10050	5.6	9003	5.8	17.2	46.0
Nov.	20054	3320	5.0	2716	5.1	9351	5.7	8428	5.8	16.5	46.5
Dec.	19680	3439	5.2	2937	5.2	9288	5.7	8199	5.94	17.4	47.0
Jan'61	19829	3456	5.1	2938	5.2	9518	5.8	8364	6.0	17.6	47.0
Feb.	18619	3614	5.5	3023	5.6	8558	5.7	7557	5.9	19.4	46.0
Mar.	20912	4266	5.2	3406	5.3	9626	5.7	8626	5.9	20.5	46.0
April	20361	3609	5.1	2720	4.8	9847	5.6	8682	5.8	17.8	49.0
May	20187	4123	4.2	2823	4.0	9345	4.7	8181	5.0	20.6	46.5
June	18221	3728	4.0	2380	3.5	8514	4.4	7414	4.6	20.4	47.0
July	20028	3068	3.9	1911	3.4	8110	4.5	1909	4.6	15.2	40.5

APPENDIX D

On-Time Performance Statistics

ON-TIME PERFORMANCE STATISTICS

Commencing in May 1959, the air carriers were required to file reports of on-time dependability at termination of all non-stop and one-stop flights. Delayed arrivals are reported in a number of categories such as (1) on-time to 5 minutes late, (2) six to fifteen minutes late, (3) 16 to 30 minutes late, etc.

Delayed arrivals may be ascribed to five principal causes:

1) Weather factors
2) Air Traffic control delays
3) Airport congestion
4) Lack of equipment
5) Mechanical

Of these five factors mechanical difficulties may be assumed to have no seasonal variation and be more or less uniform throughout the year. Air traffic control delays may be due to weather causes or such things as competitive scheduling, i.e., too many simultaneous arrivals; the effect of scheduling should be more or less constant throughout the year. Airport congestion may be due to weather, scheduling, inadequate facilities or blocked runways; only weather should show a seasonal variation as the other effects should be the same regardless of the time of year. Lack of equipment may be due to weather-caused delays, diversions or cancellations or mechanical troubles. Thus it appears that any marked seasonal variation in delays may be safely ascribed to weather causes. If such is indeed the case, one would expect to find the best on-time performance in the summer months and the worst in the winter.

In order to examine these data for the purpose of estimating effects due to weather factors, a weighted average of the on-time to 15 minutes late performance percentage was computed for each month for the domestic trunk and local service carriers and plotted on the attached graphs.

The period for which the data are available has been marked by a steadily increasing proportion of turbojet aircraft in trunk line operations. In view of the well-publicized difficulties experienced with these aircraft, a separate curve was plotted for the Boeing 707 and the Douglas DC-8 since there were enough of these two types in operation to have a pronounced effect on over-all dependability. The curve resembles a "learning" curve, showing an improvement in performance with increasing experience. The effect of the turbojets on the over-all trunk performance is quite evident from an examination of the two curves. In spite of this effect, the on-time curve for the trunk carriers shows a seasonal variation with a tendency for a maximum of performance in the late summer and early fall and a minimum in mid-winter.

The performance curve for the local service carriers is much more straightforward and less complicated than that for the trunks. This is no doubt due to the fact that the local service operation has been more stable during this period. The only new aircraft introduced by the locals has been the Fairchild F-27 turboprop, which apparently had few, if any, growing pains. The seasonal effect of the weather on the performance of the local service carriers is quite marked, with a pronounced maximum of on-time arrivals during the summer months and a corresponding minimum in mid-winter, the difference between the two being on the order of 10%.

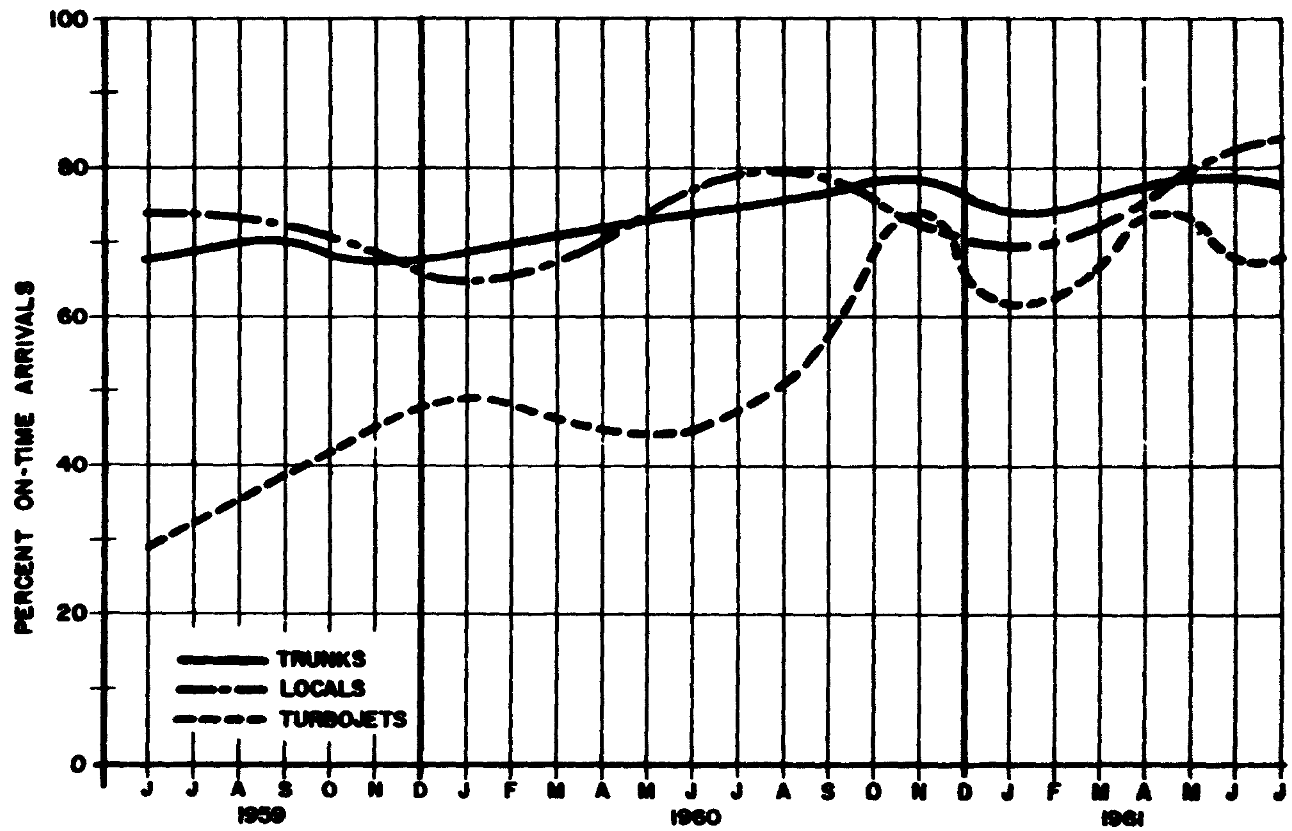

FIG. D-1. PERCENT MONTHLY ON-TIME PERFORMANCE, 1959-61
U. S. DOMESTIC AIR CARRIERS
(NON-STOP AND ONE STOP ONLY)

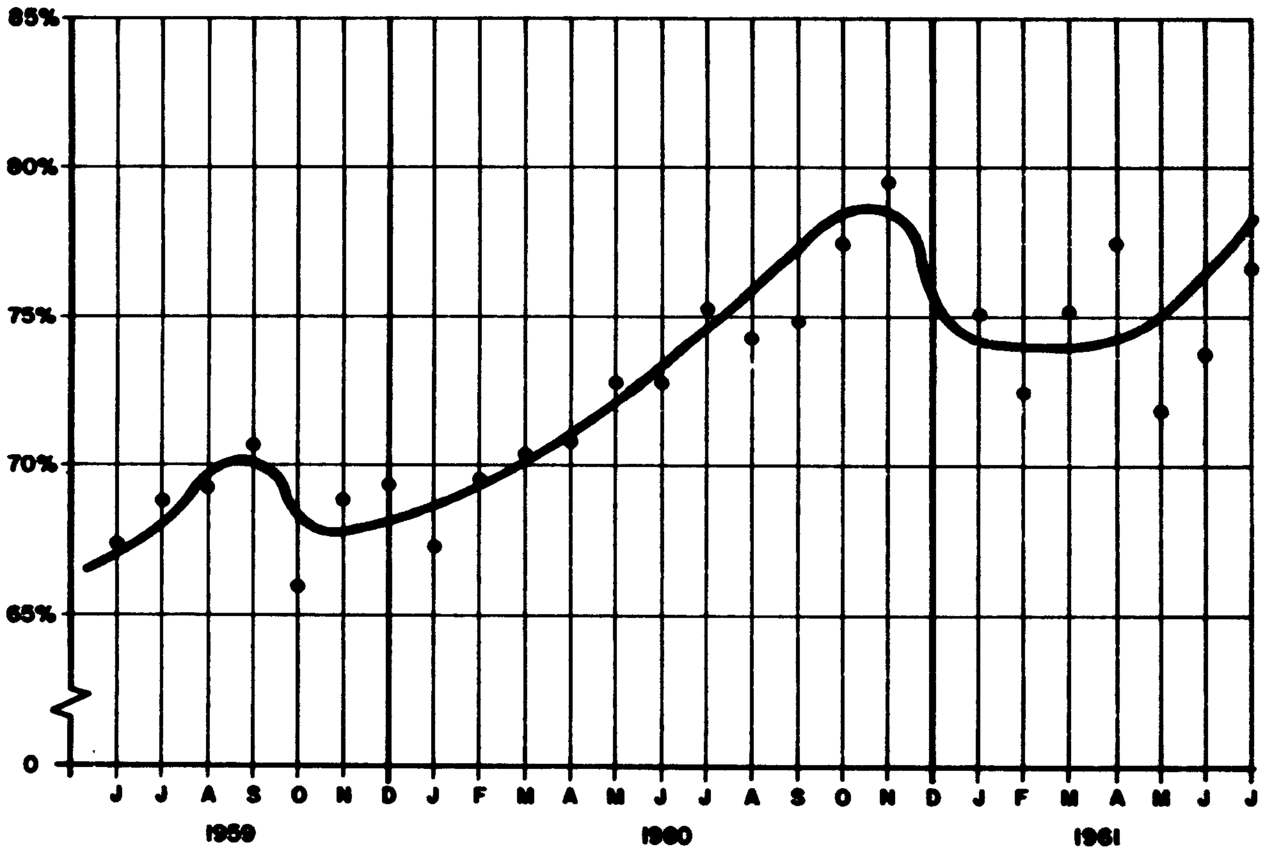

FIGURE D-2. PERCENT MONTHLY ON-TIME PERFORMANCE (NON-STOP AND ONE STOP ONLY) 1959-61 WEIGHTED AVERAGES : U.S. TRUNK CARRIER

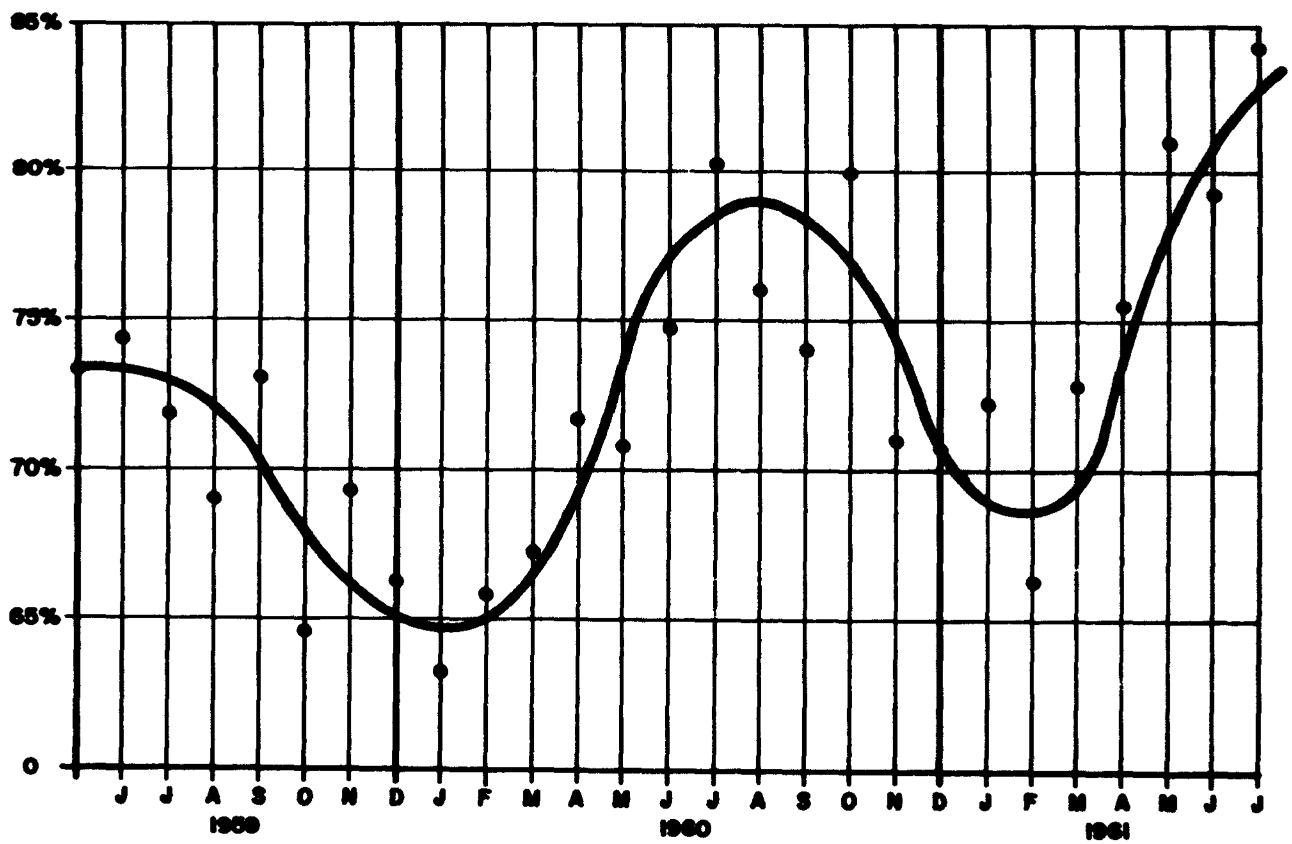

FIGURE D-3. PERCENT MONTHLY ON-TIME PERFORMANCE 1959-61
WEIGHTED AVERAGES: U.S. LOCAL SERVICE CARRIERS

APPENDIX E

Analysis of Correction Factor Applied to ATC Delays as Computed from Integrated Carrier Sample

ANALYSIS OF CORRECTION FACTOR APPLIED TO ATC DELAYS AS COMPUTED FROM INTEGRATED CARRIER SAMPLE

To ascertain to what degree the ATC delays, as obtained from a sampling of a major integrated carrier, are representative of total carrier ATC delays, an analysis of the distribution of operations of the carrier was made at all airports serviced by the carrier, and this distribution compared with the distribution of all U. S. carrier activities at these same airports.

Data were available on the carrier operations at 48 airports. At these same terminals data on total carrier operations were also available[1]. This allowed a measure of the integrated trunk operations against total operations through a group of airports at which the activity ranges from very low to very high. The 48 airports were graphically arranged in ascending order of total carrier activity to establish an activity curve. The trunk carrier operations were then plotted against this curve. The numerical differences between the slopes of the two curves allows a determination of the representativeness of the one carrier's delay as against the total delay. The major assumption here is that delay is directly related to activity - i. e., congestion.

In Figure E-1 the dotted line represents the total departures at the 48 airports. The solid line represents the trunk carrier operations. It is plotted to one tenth the vertical scale. It is apparent, that the sample carrier activity falls away from the total activity through approximately the first 35 airports and then roughly parallels the total through the remainder of the airports. To facilitate numerical measurements, the airports were divided into 6 groups of 8 airports each, and the average activity of the sample carrier and all carriers was calculated for each group. The two sets of values so obtained are plotted in Figure E-2. Successive numerical ratios were established for these 5 segments and then weighted by the levels of activity in each segment to arrive at a factor to be applied to the single carrier sample in extrapolating its delay figures to the entire carrier fleet. This factor is found to be 1.074.

---

[1] FAA Air Traffic Activity, Fiscal Year 1961

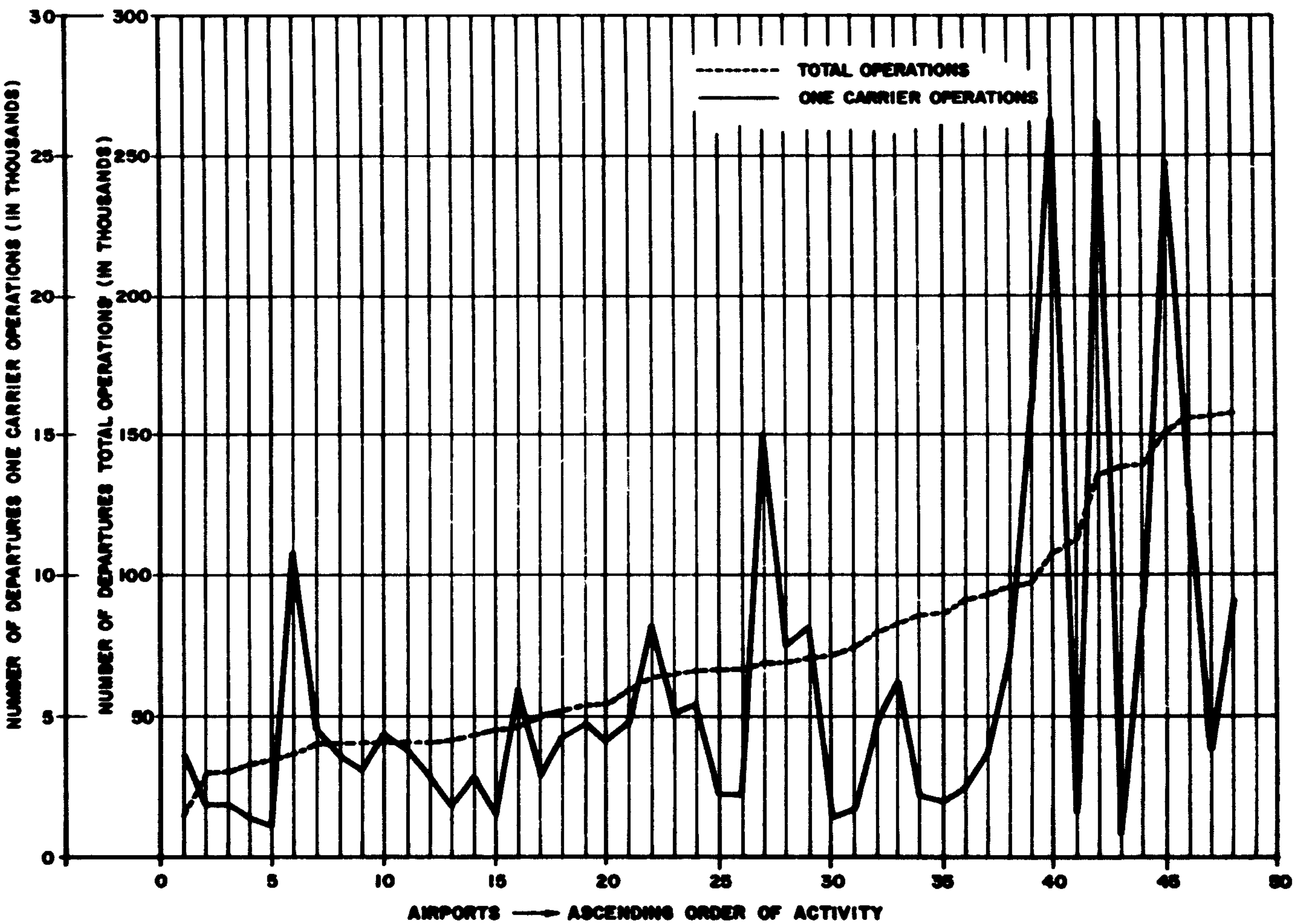

FIGURE E-1 ONE CARRIER VERSUS TOTAL CARRIER ACTIVITY

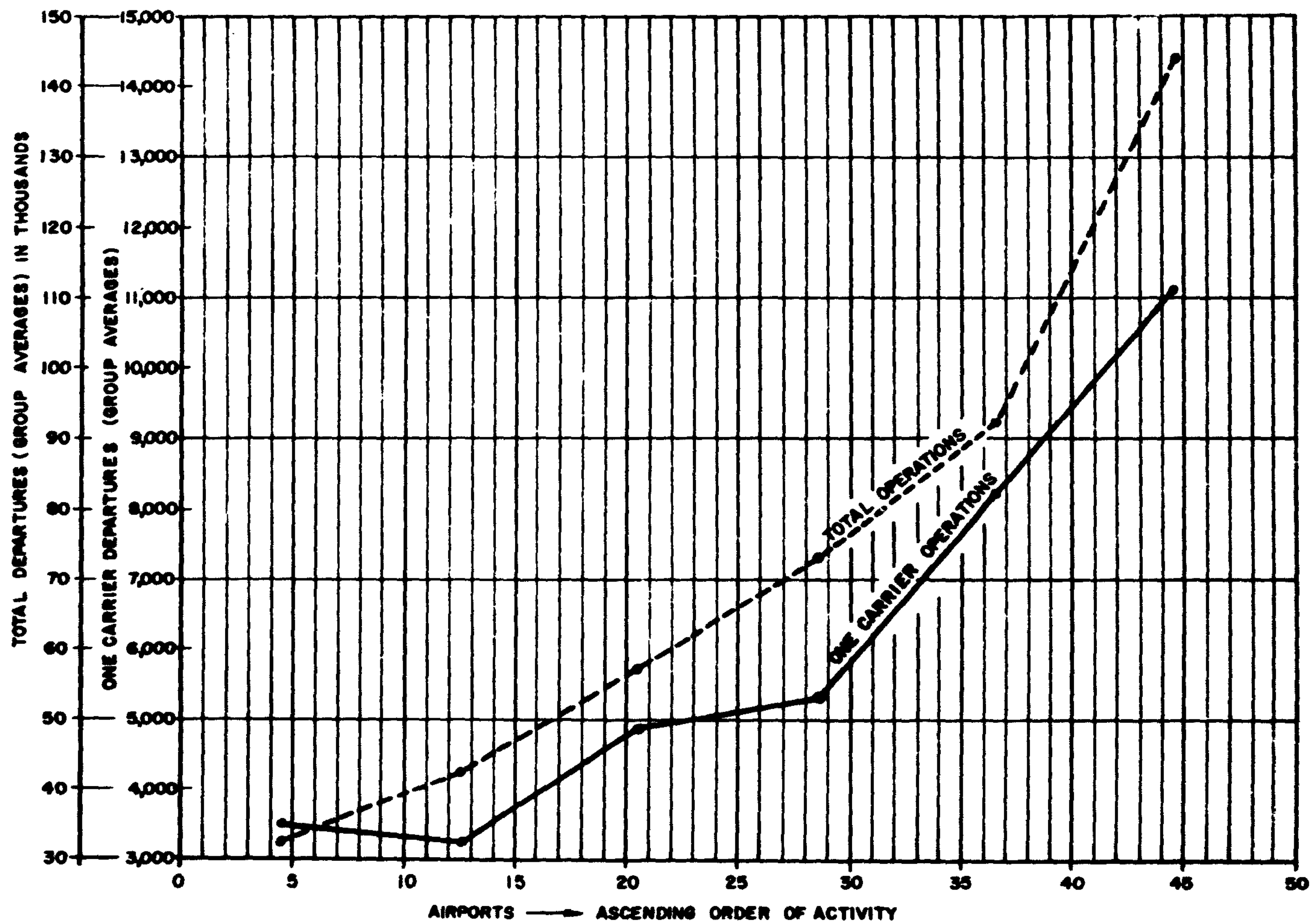

FIGURE E-2 ONE CARRIER VERSUS TOTAL CARRIER ACTIVITY AVERAGED IN GROUPS OF 8 AIRPORTS

Segment of Curve	Ratios		Ratio: Sample/Total	Average Activity		Factor
	Sample	Total		Level	Percent	
1	35/33	32.5/ 42.8	1.06/.76 = 1.4	38	10.5	.147
2	33/49	42.8/ 57.5	.67/.74 = .9	50	14.1	.127
3	49/53	57.5/ 73	.93/.79 = 1.14	65	18.4	.210
4	53/82	73/ 92.5	.65/.78 = .83	83	23.5	.195
5	82/111	92.5/ 144	.74/.64 = 1.18	118	33.5	.395
						1.074

The factor is considered to be somewhat conservative, primarily because 20 out of the 50 most active airports in the United States are not served by the sample carrier and therefore not included in the list of 48 airports.

APPENDIX F

Ontario Air-Carrier Diversions

ONTARIO AIR-CARRIER DIVERSIONS

The case of diversions at Ontario, California, is treated here as a separate example. The penalty figures estimated in this section are not necessarily representative of those produced by the average Eastern diversion terminal. However, the Ontario example illustrates the severity of the penalty when unusual weather conditions prevail at a major hub terminal, such as Los Angeles International Airport or when the diversion terminal is not set up to handle a large number of simultaneous arrivals. Moreover, all turbojets divert to Ontario when the Los Angeles terminal is closed in, in contrast to Eastern diversions where carrier aircraft divert to a large number of alternates in case of a closed-in terminal. This fact has made it possible to assess the dollar losses due to diversions at Ontario with a fair degree of accuracy.

The conditions at Los Angeles causing air carrier jet diversions to Ontario are primarily brought about by stratus clouds moving in from the Pacific Ocean. Better forecasting of this condition can save the air carriers considerable expenditures by eliminating transfer of ground handling and passenger transportation equipment to Ontario, when a forecast closed-in condition at Los Angeles does not materialize.

Of all the terminals which are used by air carrier turbojet aircraft for diversions, when destination airports are below minimums, Ontario, California International Airport occupies a unique position. It is a provisional airport with no permanent airline staffing or ground facilities except for one local service airline. Specifically, the following services, which are normally found at alternate jet terminals, are absent at Ontario:

- Jet passenger loading and unloading equipment
- Jet mail and cargo loading and unloading equipment
- Adequate gates for passenger handling
- Permanent ground transportation facilities (Bus and railroad)
- Permanent air carrier personnel.

The reason for this lack of facilities lies in the fact that Ontario is not used for regular day-to-day air carrier jet operations but comes only int action in the case of diversions from Los Angeles International Airport, from which it is about 35 miles distant. Thus, whenever diversions of jet aircraft to Ontario become necessary, special passenger and cargo ground handling equipment must be shipped by freeway from Los Angeles International Airport to Ontario. This operation requires from 1 1/2 to 3 hours each way, depending on traffic and weather conditions. A total of 15 air carriers use Ontario as an alternate, seven domestic trunk carriers, six international carriers and two local service carriers. Thus, fog conditions at Los Angeles Airport, while actually present on relatively few days out of the year, cause losses to the air carriers out of proportion to those incurred at terminals in most other parts of the country.

Another reason for treating diversions at Ontario as a separate case is that detailed cost figures could be obtained from carriers for this operation, which is not intermingled with regular scheduled carrier activities. This separates it from most other alternate terminals and provides a reasonably accurate means of assessing the dollar losses involved.

Below minimum conditions at Los Angeles International Airport start a long chain of personnel and equipment transport to Ontario Airport at odd intervals involving overtime of carrier personnel. This operation distinguishes Ontario from other alternate terminals where permanent personnel and equipment are usually available.

The costs determined by this study are composed of:

- Ground handling of passengers, mail and cargo
- Loss of passenger time
- Overtime of air carrier personnel
- Ground transportation rental by carriers
- Fuel expended by jet aircraft on the ground, waiting for gate
- Ferrying of the aircraft to departure terminal.

The local weather conditions causing diversions to Ontario or departures from Ontario rather than from Los Angeles are unique. While at Eastern terminals during bad weather conditions a large part of the Atlantic Coastal region is closed in, affecting such terminals as Boston, New York, Philadelphia, Washington and Baltimore, a fog condition at Los Angeles is often purely local, extending only over 5-10 miles. Moreover, Ontario Airport is separated from the Los Angeles basin by a 1000 ft. mountain barrier which blocks the movement of the fog to Ontario. This means that the Ontario Airport, which readily accommodates turbojets and has freeway facilities into the city of Los Angeles, is usually open whenever landings at Los Angeles are prevented by fog.

Table 1 depicts the number of arrivals at Ontario during the calendar year 1961 and for the additional months January, February 1962. The table has been plotted in the form of a bar chart in Figure 1, which clearly shows the seasonal nature of the diversions.

The winter of 1961-62 had an unusually high incidence of diversions, totaling 548 arrivals from November 1961 to February 1962 with the single month of December accounting for 333 diversions alone. Table 2 shows one peak day, December 22, 1961 where a total of 61 turbojets and 9 propeller aircraft were diverted to Ontario involving 5240 passengers. The fact that such operations have extreme peak periods where the activities by far exceed the capability of the facility to handle the traffic, further complicates the task. While the major trunk carriers have 10 to 14 gates each available at Los Angeles for loading and unloading passengers, there are only 2 gates each at Ontario. Thus, arriving aircraft must either wait on the field with engines running or land at outlying terminals such as Phoenix, Salt Lake City, or Las Vegas, waiting on the ground until gates are available at Ontario. On the above peak day in December, 20 turbojets waited on the field at Ontario, with engines running for as much as 2 hours before passengers and cargo could be unloaded. The dollar

Table F-1. Diversions to Ontario International Airport, California
January 1961 to February 1962

Air Carrier	1961												1962	
	J	F	M	A	M	J	J	A	S	O	N	D	J	F
UAL	2	6	4			4		8	7	6	15	73		
AAL						3		8	3	7	16	71		
TWA			1			2		12	2	10	12	60		
CAL		1	1	1		3			4	4	7	36		
PAWA						1		3	1	3	4	23		
WAL	1					2					3	23		
BAL											4	16		
DELTA								2		1	1	13		
SAS						1			2	2	1	3		
Air France								1				5		
Mexicana												4		
Nat. A. L.										1		3		
J. A. L.												1		
Pres. A. L.												1		
Northwest												1		
Total Per Month	3	6	6	0	0	16	0	34	19	34	63	333	72	80
TOTAL FOR ENTIRE PERIOD: 646 Aircraft														

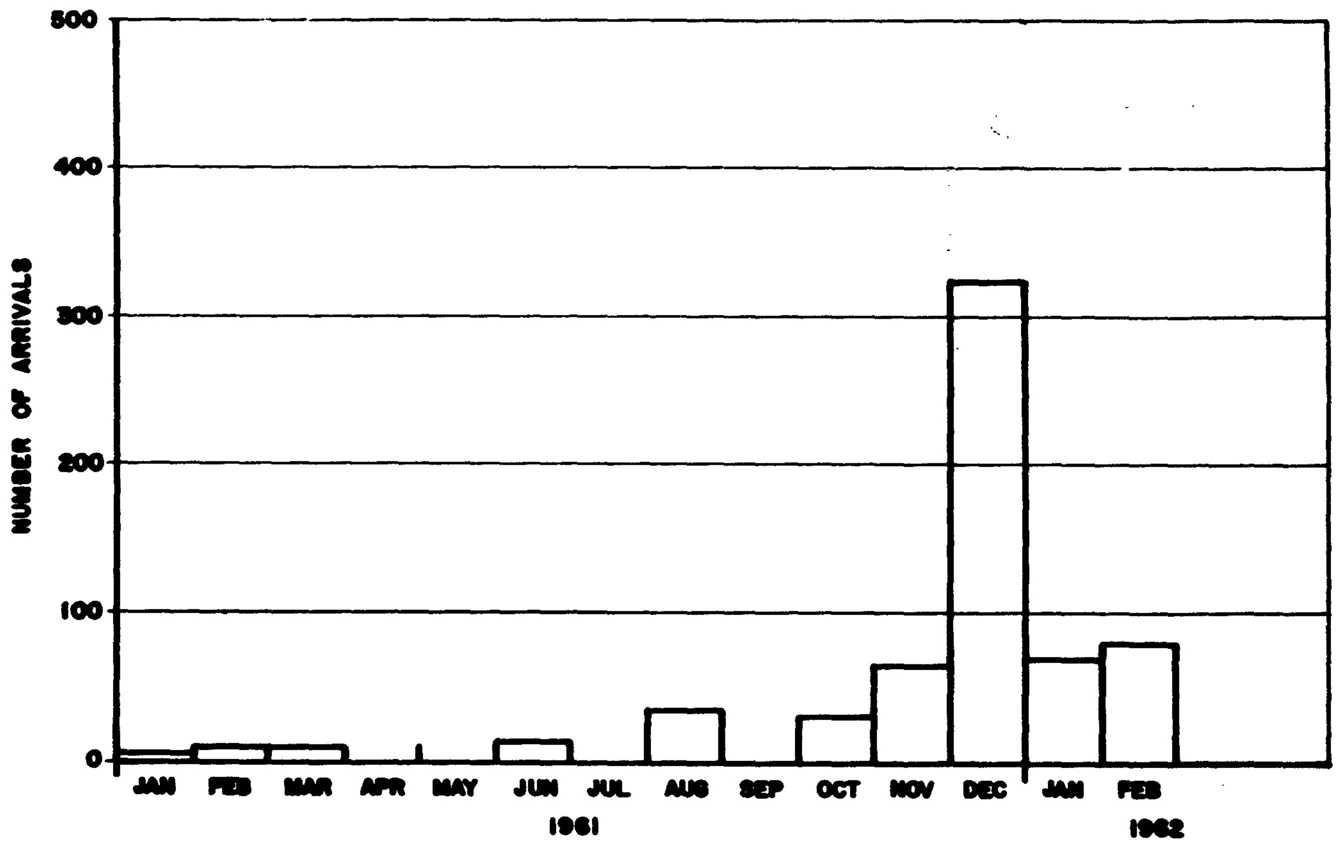

FIGURE F-1. ONTARIO INTERNATIONAL AIRPORT, ALTERNATE OPERATIONS 1961 (ARRIVALS ONLY)

Table F-2. Diversions to Ontario International Airport - Peak Day December 22, 1961

		ARRIVALS			DEPARTURES				
Time In	Carrier	Flight No. In	Plane No.	Passengers Off	Time Out	Flight Out	Plane No.	Passengers Out	Aircraft Type
0039	TWA	65	795	79	0501	84	795	102	707
0138	AAL	7	513	121	1121		Ferry		707
0258	UAL	94	2923	40	0513		2923	86	DC-8
0307	AAL	83	547	61	1011		Ferry		707
0309	TWA	15	737	60	0440	15	727	96	707
0352	UAL	891	2632	76	1002		Ferry		DC-8
0358	AAL	21	523	45	1243		Ferry		707
0434	Pres. A. L.		2283	Ferry	2390		2283	56	DC-7
0501	TWA	85	2792	90	1055	66	2792	97	707
0508	UAL	855	2216	67	0632		2216	57	DC-8
0514	NAL	31	6572	47	1230	32	6572	96	707
0641	UAL	879	2209	115	2253	866	2209	76	DC-8
0651	PanAm		706	Ferry	1150	124	706	44	707
0705	PanAm		724	Ferry	1139	817	724	139	707
0924	UAL	835	7217	102	1402	820	7217	89	720
0925	TWA	50	7745	72	1615		7745	52	707
1608	AAL	83	547	47					707
1613	UAL	90	8026	52	2130	890	026	74	DC-8
1625	UAL	853	2207	79					DC-8
1630	AAL	33	510	96					707
1633	Delta	841	912	71	1937	894	912	49	880
1649	AAL	11	524	7					707
1654	AAL	23	507	100					707
1658	Mexicana	910	LAU	36	2152	90	LAU	46	DC-6
1700	PanAm	890			2140	901		54	707
1701	PanAm	812	729	110	2302	811	729	96	707
1703	UAL	771	2215	87					DC-8
1710	WAL	627	144	109					720
1719	BAL	23		29	1918	54		19	F-27
1730	Air France (TAI)	001	HSK	52					707
1750	BAL	47		27					F-27
1752	UAL	833	2237	94					DC-8
1804	TWA	61	740	62	1947	61	740	56	707
1816	TWA	69	734	124	2120	69	734	78	707
1853	TWA	11	741	87					707

Table F-2. Diversions to Ontario International Airport - Peak Day
December 22, 1961

ARRIVALS					DEPARTURES				
Time In	Carrier	Flight No. In	Plane No.	Passengers Off	Time Out	Flight Cut	Plane No.	Passen-gers Out	Aircraft Type
1858	UAL	859	2207	120					DC-8
1903	AAL	5	503	86					707
1914	UAL	95	2924	102					DC-8
1941	CAL	3	785	122	2221	18	785	56	707
2009	AAL	805	350	Frgt.					DC-7
2014	AAL	73	532	95					720
2017	CAL	291	249	43					Viscount
2028	AAL	55	550	93					720
2031	CAL	9		56					707
2036	AAL	627	704	Frgt.					DC-6
2039	UAL	891	2238	94					DC-8
2043	WAL	638	3143	103	2350	502	143	97	720
2059	Delta	821	801	83					880
2133	WAL	637	3141	81					720
2206	TWA	167	8818	84					880
2211	TWA	1	737	94					707
2216	UAL	815	4004	85					720
2217	TWA	65	2795	75					720
2220	AAL	61	534	92					707
2226	TWA	77	742	113					707
2228	CAL	755		78					DC-7
2231	UAL	781	4018	107					707
2036	AAL	75	511	80					707
2241	CAL	5		96					707
2243	BAL	25		25					F-27
2250	UAL	817	2632	94					DC-8
2254	CAL	53		85					707
2258	AAL	25	539	68					707
2259	UAL	865	2239	106					DC-8
2317	UAL	795	4019	110					720
2332	TWA	143	8812	78					880
2336	UAL	702	4013	82					720
2349	WAL	63		105					707
2350	CAL	257	243	42					Viscount
2354	PanAm	818		120					DC-8
	TOTAL ARRIVALS				TOTAL DEPARTURES				
8	Propeller Aircraft				3	Propeller Aircraft			
61	Turbojet Aircraft			5240	19	Turbojet Aircraft			1615

losses due to this instance alone considering passenger time delay, aircraft delay and fuel consumed by idling engines, amount to over $50,000.

In addition to the actual diversions, numerous "dry runs" due to inaccurate terminal forecasts add to the weather losses. When Los Angeles is forecast to be closed, and ground crews as well as transportation facilities are dispatched by the carriers to Ontario several hours prior to scheduled aircraft arrivals, it often happens that the below minimum conditions do not materialize at Los Angeles and aircraft will not have to be diverted. Such "dry runs" amount to about 50% of all operations.

During periods when the Los Angeles terminal continues to stay below minimums for extended lengths of time, Ontario is also used for provisional departure operations, with departing passengers being shipped by surface transportation from Los Angeles to Ontario. This usually involves a 3 hour departure delay for each passenger with resulting additional delays in arriving at their destination and missed connections. It was found that 38% of all arriving aircraft also departed from Ontario on the return trip with outbound passengers, while the remaining 62% were ferried out empty. Outbound fuel totaled 1,590,375 gallons for the year 1961.

Passenger Handling Costs

The methods of handling ground operations during diversions vary with the air carrier. At least one major carrier maintains a minimum of equipment at the field and contracts with outside firms for the major jobs of passenger ground handling and aircraft servicing. The remaining carriers ship primarily their own ground handling facilities and personnel to Ontario during diversion. An additional expense derived from the fact, that regular carrier personnel are transported to Ontario from Los Angeles on an overtime basis to satisfy demands during periods of peak diversions.

Analysis of a set of cost figures concerning contracting with outside firms for passenger and cargo ground handling services indicates that this activity accounts for 27% of the entire operation. Unit costs are $9.70 per arriving or departing passenger. The remainder, where carriers utilize their own personnel, amount to 73% of the entire operation and compute at the higher rate of $17.30 per passenger. The total costs involved in ground handling for the year 1961 add up to $712,000 per annum. Included in this figure are "dry runs" where the weather in Los Angeles was forecast below minimums. Ontario operation was set in motion, but the diversion did not materialize. Dry runs alone amounted to $237,000 in 1961.

Passenger Delay Time

A normal total delay of 3 hours per passenger was assumed here. This is a conservative assumption since many passengers suffer additional delays due to missed connections, frequently involving overnight stays. The total number of passengers involved in Ontario diversions during 1961, both deplanning as well as originating was 46,000. This results in a minimum of 140,000 hours of passenger delay. An average cost of passenger delay, computed elsewhere in this study at $6.50 per hour, yields a total annual loss of $910,000.00.

Ferrying Costs

The costs of ferrying empty jet carrier aircraft from Ontario to Los Angeles, when the weather improved, account for additional penalties. Approximately 318 such ferry flights were carried out in 1961 at an average of 25 minutes ferrying time. This amounts to a total cost of $127,000.

Summary Costs of 1961 Ontario Diversions

The total economic penalty due to diversions caused by below minimum weather at Los Angeles in 1961 is therefore:

Direct passenger, cargo and mail handling costs	$ 712,000.
Loss of Passenger Time	910,000.
Aircraft Ferry Costs	127,000.
TOTAL	$1,749,000.

PROJECTED DOLLAR LOSSES DUE TO ONTARIO DIVERSIONS IN THE 1960 - 1975 PERIOD

In attempting to estimate the growth of unscheduled operations at Ontario in the 15 year period ahead, several factors must be considered.

First, the growth in number of turbojet flights during this period into Los Angeles airport will be smaller than the increase in carrier jet flights over the entire U.S. The transcontinental route from New York (or Washington, Baltimore) to Los Angeles was the first one to be implemented with jet equipment and consequently has already achieved a good proportion of its growth potential. Thus, while nationally the number of jet flights are predicted to increase from a total of 130,000 in 1960 to 3,220,000 by 1975[1], a ratio of 25:1, jet flights into Los Angeles cannot be expected to increase by the same factor. A conservative estimate can be obtained from the fact that the present installation of an additional runway will approximately double the acceptance rate. Moreover, the replacement of the major portion of the remaining piston flights by turbojet equipment is estimated to increase the total by an additional 50%. Thus, a factor of 3:1 for the increase in jet flights into Los Angeles during the period 1960-1975 is considered a conservative assumption.

The second item affecting the cost of diversions into Ontario will be the addition of permanent ground handling facilities. However, since the use of these facilities is contemplated only for unscheduled operations, i.e., during the relatively infrequent periods of diversions, they will of necessity remain at a practical minimum for obvious economic reasons. In view of this fact additional equipment and ground handling personnel will continue to be shipped to Ontario whenever required, except that with expanded permanent facilities this operation will likely be reduced.

[1] "Forecasts of Air Traffic Activity, Cont. U.S., 1960-75", FAA, Traffic Analysis Branch.

Third, over a period of 15 years there will be variations in the number of below minimum days in Los Angeles from year to year. The winter of 1961-62 saw an unusually high number of diversions as compared with past years. However, it is impossible to predict what will happen to the local weather conditions at Los Angeles in the future.

The last point to be made here is that in the years to come there will undoubtedly be a lowering of jet minimums. Ultimately it is expected that all major terminals will be equipped with complete all weather landing systems, which would practically eliminate diversions of air carrier jets at these terminals.

In summing up, all the above factors will have an effect on the future losses due to diversions at Ontario. The trends to counteract each other, thereby partially cancelling out any increase or decrease in the number of diversions. For this reason it will be assumed that the dollar losses due to diversions at Ontario will remain unchanged in the 1960-1975 period.

APPENDIX G

Acknowledgements

ACKNOWLEDGEMENTS

The following personnel took part in this study:

Walter L. Koch, E. Bollay Associates, Inc.
Rear Adm. F. A. Berry, USN (ret.), E. Bollay Associates, Inc.
Professor M. Andron, University of California, Santa Barbara, California
Captain C. E. Recknagel, United Air Lines
John G. Cronin, Aerometric Research, Inc.

Data furnished by the Traffic Analysis Branch, Federal Aviation Agency, and the Civil Aeronautics Board were most helpful and furnished the basis for the projections made throughout the study. Operating and maintenance statistics made available by United Air Lines, American Air Lines and Trans World Air Lines, were of great assistance in the air carrier portion of the study.

In addition, the following individuals assisted the authors of this report by advice, comment and suggestions:

David Robertson, United Air Lines
R. A. Rowland, American Air Lines
Woodruff de Silva, Ontario International Airport, California
Robert Hamilton, Ontario International Airport, California
Ralph Kuhli, National Safety Council
C. W. Reynolds, U. S. Weather Bureau
T. F. Gladney, U. S. Weather Bureau
Everett Bosworth, Federal Aviation Agency
Cdr. J. W. Hinkelman, Federal Aviation Agency
C. J. Watson, Federal Aviation Agency
Royce Ainsworth, Federal Aviation Agency
Frank Carroll, Federal Aviation Agency
W. D. Markey, Civil Aeronautics Board
R. Hughes, Civil Aeronautics Board
W. Hollowell, Civil Aeronautics Board
William Lawton, National Business Aircraft Association
P. A. Fruehauf, United Air Lines
W. E. Rhoads, United Air Lines
W. Pitt, United Air Lines
R. Griffin, Associated Aviation Underwriters
J. Murphy, United Air Lines
L. Straw, United Air Lines
H. T. Harrison, United Air Lines
M. E. Balzer, United Air Lines

J. W. Grewell, Federal Aviation Agency
E. J. Minser, Trans World Air Lines
J. A. Browne, Trans World Air Lines
P. E. Kraght, American Air Lines
D. R. Petty, United Air Lines
R. Seaman, Federal Aviation Agency
W. Ashby, Federal Aviation Agency
G. Lanning, Federal Aviation Agency
N.A. Lieurance, U. S. Weather Bureau
T. Gleiter, U. S. Weather Bureau
J. Lederer, Flight Safety Foundation
C. E. Veigle, American Air Lines
D. C. Davis, American Air Lines
John Beck, Trans World Air Lines
James Davis, Trans World Air Lines
T. Plunkett, United Air Lines
W. E. Larned, United Air Lines
R. R. Rapp, RAND Corporation

☆ U. S. GOVERNMENT PRINTING OFFICE : 1963 O - 678080